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Contents

Urban Transportation Planning Under Energy Constraints

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Current knowledge concerning the impact of limited fuel availability on urban travel behavior is reviewed, and the application of this information to urban transportation planning is discussed. The 1973-1974 oil embargo is viewed as a short-term perturbation in the energy-transportation system that resulted in temporary changes in travel behavior. Short-range energy contingency planning can benefit most from the knowledge gained during this period. Energy contingency planning should emphasize non-capital-intensive policies that can be easily and quickly implemented to conserve fuel. The information gained during the embargo does not appear to be directly applicable to long-range urban transportation planning under energy constraints. Long-range urban transportation plans do not appear practical at this time because of the lack of information concerning the impacts of fuel availability on travel and living patterns. It may therefore be more beneficial to develop plans that have the flexibility to include this information as it becomes available. A standardized definition of fuel availability should be determined, and a mechanism for capturing fuel allocation and consumption statistics on a disaggregate level should be established. Trends in the attitudes of consumers toward the energy situation and transportation-related behavioral changes that result from these perceptions should also be monitored.

Since the 1973-1974 oil embargo, there has been considerable interest in national energy futures and in the analysis of the sensitivity of transportation-related energy consumption to alternative transportation and land-use policies. Much of the current literature is devoted to the review and analysis of strategies to reduce automobile fuel consumption in urban areas where approximately 34 percent of total transportation-related energy consumption occurs. These trips account for approximately 98 percent of the fuel consumption for urban passenger travel and approximately 92-95 percent of total vehicle person trips (1).

Traditionally, the urban transportation planning process has not dealt with the availability of fuel. Before the embargo, there appeared to be little need to develop urban transportation plans or strategies to cope with this possibility. Since the embargo, however, and after analysis of its impacts on urban travel behavior, planners have begun to reevaluate the urban transportation planning process in light of dwindling worldwide oil reserves.

IMPACT OF THE OIL EMBARGO ON TRAVEL DEMAND

The energy shortage of 1973 and 1974 did not last long enough for an evaluation of the long-term impacts of a reduction in fuel supply on travel behavior to be made. From the studies conducted, however, several general statements can be made about the short-term impact of the embargo on individual travel patterns.

The propensity for an individual or a household to change travel behavior under energy constraints appears to be most heavily influenced by income (2-5). In general, higher-income groups have more flexibility in their travel behavior and are more willing to absorb the increased cost of work-related travel without changing travel modes. They tend to conserve fuel by reducing the amount of discretionary travel. The emphasis on conservation is placed on shopping or social-recreational travel through the implementation of "trip chaining".

Lower-income groups generally have less travel flexibility, make fewer discretionary trips, and thus are more inclined to make adjustments related to work travel in an effort to conserve fuel. In the 1973-1974 embargo, this group was the most likely to shift to alternative modes of transportation and was also more likely to retain their changed travel patterns when the embargo was over.

Several other parameters, some of which are related to income level, also appear to have influenced travel decisions during the embargo. These include family size, automobile ownership, education and occupation of the head of the household, location (urban, suburban, or rural), city size, and the level of service of public transit.

Heads of households that have high gasoline price thresholds (i.e., the perceived price per liter of gasoline that would create a significant change in travel behavior) generally have an annual income of more than $15 000, are fairly well educated, and would rather pay higher prices for gasoline than have gasoline rationing. In contrast, houshold heads with low gasoline price thresholds earn less than $15 000/year, have lower education levels, and prefer rationing to substantial gasoline price increases (4).

Those families most likely to switch from the automobile to another travel mode are described as having three or more members and two or fewer automobiles, living in an urban area, and having an annual income of less than $15 000. The household head is over 30 years old and employed as a white- or blue-collar worker. Those most likely to drive their automobiles less frequently are described as families in cities of more than 25 000 population and whose heads of household are employed in managerial or professional positions. Those most likely to retain their new behavior patterns were families with three or more members, one automobile, and an annual income of less than $10 000 who lived in a city with a population of 2500 or more (2). Although the higher-income groups did not tend to change travel mode during the embargo, one study (3) showed that there is a high potential for a shift to transit for the work trip for this group provided an adequate level of service is supplied.

Analyses of changes in traffic volume during the embargo in various parts of the country (6-10) have led to the conclusion that most efforts to conserve fuel were made through the nonwork trip. The largest percentage change in traffic volumes occurred on weekends in both urban and rural areas. Lee (6) suggests that the larger relative reduction in leisure trips was caused in part by the greater uncertainty of obtaining fuel for these trips and may not reflect a simple priority ranking of trip purposes.

In some of these same studies (6, 9, 10), the availability of automotive fuel was found to be a much more important factor in determining travel demand than the actual retail price. The elasticity of demand in relation to price appears to vary with trip purpose, but it is small (-0.1 to -0.5) for all types of trips. This is true at least for the range of prices studied. The impact of the availability of fuel also appears to vary by trip purpose, but only one study has attempted to quantify this differential. Lee's analysis (6) indicated that weekday trips in California were more sensitive to increases in gasoline price than weekend trips (-0.263 versus -0.174). However, the percentage reduction in leisure travel was greater than that in work travel because the uncertainty of obtaining fuel on weekends made the "true" price of leisure travel more than twice that of work travel.

At this time, attempts to restructure the urban transportation planning process to accommodate the impacts of energy constraints can only be calibrated against information obtained during the oil embargo. This may ultimately prove to be unsatisfactory since the long-term response to energy constraints may not be the same as the short-term response.

PLANNING FOR ENERGY CONSTRAINTS

Hartgen (11) has evaluated the capability of urban transportation planning system (UTPS) procedures to deal with energy constraints. He concludes that the UTPS process can be used to determine the sensitivity of fuel consumption to certain energy policies (e.g., speed reductions, increased vehicle efficiency, and carpooling). However, the process is generally incapable of analyzing the impacts of policies such as rationing or bans on Sunday driving.

By using calibrated models from UTPS and other transportation planning packages, the impacts of certain energy policies on travel behavior can be estimated through sensitivity analysis techniques. There appear, however, to be some basic pitfalls in using the results of sensitivity testing to evaluate policy decisions. The individual and aggregate behavioral response over the long term may not be identical to the short-term response. In addition, the required policy actions may require limitations on fuel or the price of fuel to exceed the range of the values used in model calibration. For example, increasing automobile occupancy for the work trip to approximately 2.0 passengers/vehicle on the average would yield significant energy conservation results. It has been reported, however, that the estimated maximum national average automobile occupancy obtainable through carpool incentives is between 1.4 and 1.7 passengers/vehicle (12). Sensitivity tests may yield unrealistically high estimates of the fuel conservation advantages of carpooling.

In well-established urban areas, where the largest gains in fuel consumption can be made, implementing policies to redistribute urban activity may be extremely difficult because of the high potential for social, economic, and political pressure to maintain existing living, working, and shopping patterns. Controlling the location of new growth to conserve fuel may be possible, but the energy saved by such action in the nation's standard metropolitan statistical areas (SMSAs) would be insignificant compared with the energy consumed in existing living and travel patterns.

Another significant deficiency in sensitivity testing is the lack of available information on the combined effects of two or more policies. During a fuel reduction period, several energy conservation policies may be required simultaneously. A review of the energy conservation potential of urban mass transit conducted by the congressional Office of Technology Assessment (OTA) suggests that the most effective ways of accomplishing energy conservation "involve emphasis on disincentives to auto use coupled with transit use incentives" (1). Sensitivity analyses on existing models could only detect these combined effects if the cross elasticities were known or assumed.

There is little quantitative information available by which to test the results of sensitivity analysis. This is especially true for an environment of restricted fuel availability. Current capabilities for testing the sensitivity of fuel consumption in urban passenger transportation to specific conservation policies, either individually or in combination, are based on relations developed during periods of unlimited fuel availability. The question that arises is, Do these relations apply to environments of restricted fuel availability? A definitive answer is not available. It could be argued, however, that limited fuel availability is in itself an inducement to conserve and so travelers would be even more sensitive to conservation policies during a fuel shortage. Relations developed based on nonshortage system changes would therefore yield conservative estimates during a period of shortage.

To effectively use the UTPS or similar procedures for planning purposes, the planning process will have to be restructured to include better recognition of the impacts of national energy futures on urban mobility. Only in this way can the effectiveness of specific energy conservation policies be determined. Particular attention should be given to the effect of fuel availability on trip generation, distribution, and mode choice at the urban level. The long-range impacts of reduced fuel availability and conservation policies on land-use distribution should also be determined.

Several attempts have been made to evaluate such future impacts by indirect methods. These have generally taken the form of projections of various levels of transportation demand by mode with forecasts of energy consumption for alternative future transportation technologies. Several of these studies attempt to describe the cause-effect relation between supply and demand.

One attempt to quantify this relation was developed by OTA (1). A log-linear regression analysis that used national data for 1971 to 1974 generated a relation between the annual growth rate in transit patronage and the annual growth rate in vehicle kilometers of highway travel. Alternative future national levels of fuel consumption were then translated into annual growth rates in vehicle kilometers of highway travel by using assumptions as to the future proportion of available petroleum that would be used as fuel for highway travel and the average fuel economy of highway vehicles. Growth rates for vehicle kilometers of highway travel were then used to forecast future transit patronage under each energy alternative. Although this represents one attempt to formulate a relation between supply and demand, it assumes that the historical relation between transit and highway travel will prevail under all conditions of fuel availability.

Beltrami and others (13) propose an analysis technique that is not constrained by this assumption. Most significant in their approach is their incorporation into the automobile trip interchange forecasting technique of the delay experienced by motorists as they search and wait for gasoline. In incorporating the availability of fuel into the automobile time parameter, however, assumptions are made that this delay is equally distributed across all types of trips and that it has the same significance for all automobile trips as a reduction in travel speed. These assumptions are not substantiated.

The controlling variable may in fact be the degree of the limitation of fuel availability. Fuel availability has been identified as the variable that was most influential in causing changes in travel behavior during the oil embargo. But fuel availability has not yet been quantitatively defined. Quantification of this parameter and its relation to travel behavior appears to be an essential ingredient in the restructuring of the urban transportation planning process to forecast future travel behavior under energy constraints.

The limited available information on the impact of fuel availability on urban travel all resulted from the short-term 1973-1974 perturbation in the energy-transportation system. The applicability of this information to long-term planning is doubtful. Since the oil embargo was perceived by the general public as a temporary situation, the actions taken to reduce travel may also have been viewed as temporary. For example, while total purchases of automobiles fell sharply, no shift to smaller automobiles was observed (14). Smaller, more efficient automobiles might be an attractive alternative in a long-term environment of restricted fuel. It takes time for many automobile purchasers to reach this conclusion and act on it. The oil embargo was too short to allow for such long-term adjustments in consumer behavior, so analysis of the changes that occurred in that period would not necessarily apply to long-range planning.

Another difficulty with applying information gathered from the oil embargo to long-range planning is that most long-term policies that would reduce energy consumption were not implemented. Thus, no empirical evidence exists to evaluate their impacts. The effects of improved technology, changes in transportation systems, and shifts in land-use activity can only be speculated on. It may therefore be necessary to develop two different approaches to planning under energy constraints—one for short-term planning and one for long-term planning.

Short-Term Energy Contingency Planning

A short-term embargo-type shortage will be characterized by a duration of from several months to possibly one or two years. The availability of gasoline will be sharply curtailed, but public and private decisions will be based on the assumption that fuel supplies will return to normal at some future date. There will probably be another rapid increase in the price of gasoline and, as before, there will be temporary changes in travel behavior. In general, the picture will be very similar to the embargo of 1973 and 1974.

Planning for the short-term fuel shortage should stress policy alternatives that can be applied easily and quickly and yield significant results. Short of rationing, such policies could include

1. Stronger enforcement of lower speed limits;
2. Carpooling and vanpooling with or without priority lanes;
3. Automobile disincentives such as driving bans and increased parking charges;
4. Transit incentives such as reduced or free fares and service improvements within the limits of system capabilities;
5. Rerouting or rescheduling of bus fleets to increase system efficiency; and
6. Efforts to reduce congestion, such as staggered work hours, a four-day workweek, and time-differential transit or parking fees.

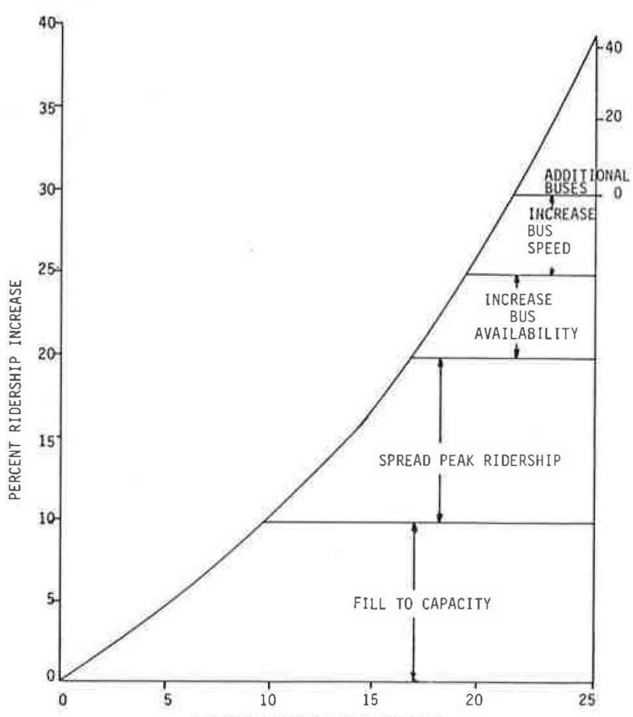
Sensitivity analysis is useful in evaluating the potential energy conservation effects of these policies, but it should be limited to the feasible range of values of the independent variables. A priority plan that rank orders the potential impact of each of these measures, individually and in combination, should be developed and tested for each urban area through the use of UTPS or some similar package. Figure 1, which represents such a priority system for Dallas, Texas, shows the percentage of national fuel deficit at which speculative increases in transit ridership would occur and describes the order of policy implementation and the projected limits of increased capacity in Dallas (15). If the fuel deficit exceeds 10 percent (the level during 1973 and 1974), action other than using the space on existing transit runs will be necessary. Policies for spreading peak ridership that could be tested by UTPS include staggered work hours, shorter workweeks with variable days off, and flexible work hours. If the next set of actions is required, the options that could be tested include maximizing availability of the current bus fleet by increasing the maintenance budget, reducing the number of out-of-service buses, and shifting buses to lines that experience the greatest increases in ridership. Finally, methods for increasing bus speed that can be tested include designation of bus-priority lanes, signal preemption, or the increased use of express service. Increasing the fleet size through the purchase of new vehicles is not generally feasible in the short term because of the capital investment required and the time needed for purchase and delivery (one to two years).

In short-term energy contingency planning, emphasis should be placed on

1. Analysis of the relations between fuel supply and travel demand detected during the oil embargo,
2. Analysis of disaggregate travel behavior characteristics and attitudes during the embargo, and
3. Non-capital-intensive policies to conserve fuel.

With or without rationing, the public will be required to adjust their travel behavior based on reduced availability of fuel. It is important to analyze the knowledge gained during the 1973-1974 embargo with respect to the impact of fuel availability on travel behavior so that it can be applied in short-term contingency planning. This

Figure 1. Effect of increases in ridership on bus use in the Dallas transit system.



may not be a simple task because much of the information that would be useful does not appear to be available. As part of a research effort at Michigan State University, agencies in the 36 states that contain the 79 largest SMSAs and the District of Columbia were surveyed in an effort to collect county-level data on gasoline consumption or availability for the period 1972 through 1975. Only nine respondents indicated that the information was available either directly or indirectly through tax reports. The remainder (four states did not respond) indicated that the information was available only on an aggregate statewide basis and that there was no method of obtaining this information at the county level.

Another important aspect of contingency planning is understanding the impact of policy decisions on travel behavior and hence on energy consumption. Care must be taken not to be misled by sensitivity analyses that indicate that particular policy measures will yield significant results based on unrealistic assumptions about induced changes in travel behavior. Potential gains that were to result from a shift from the private automobile to public transit during the fuel shortage were generally overestimated.

Long-Term Planning

A long-term decline in the availability of fuel is characterized in much of the literature as a gradual annual decline in fuel availability over the next 20 years and beyond (1, 16, 17). Because the actual rate of decline is difficult to predict, speculation often centers on two or more possibilities and the ramifications of each. This slower rate of decline in the availability of fuel will be accompanied by changes in transportation technology, probable shifts of financial resources to nonhighway modes, longer-lasting adjustments in societal attitudes and behavior, and shifts in land-use pattern (17).

Modification to the long-term planning process should stress the more basic changes in the structure of cities and transportation systems. The effect of the transportation system on long-term changes in land use and travel behavior must be better understood. Sensitivity analysis may be helpful in this respect but only as a guide on which direction will yield the greatest return for the investment. Conclusions reached by sensitivity analysis will be suspect because the reaction of travelers to an extended fuel shortage will most likely be different than it was during the 1973-1974 period. Therefore, the empirical data collected during that shortage will not necessarily be valid for long-term planning, and the relations developed from those data should not be extrapolated. On the other hand, the use of purely theoretical relations is suspect because of a lack of knowledge about long-term patterns of human behavior, especially in environments we have never encountered.

Many of the policies discussed for energy contingency planning may also be applicable in the long term. It is more realistic, however, to assume that the gradual nature of the decline in the availability of fuel will be accompanied by policies that will seek parallel improvements in the transportation sector. Such policies include

1. Encouragement of improved technology, such as more efficient automobiles and use of alternative fuels in the transportation and industrial sector (this would include the advancement of the electric automobile);
2. Transportation system changes, including improved transit systems, and automobile-free zones and restricted traffic zones;
3. Redistribution of urban activities, including more efficient settlement patterns, higher density, and more efficient patterns of work location (this would result in shorter work trips and allow for transportation system changes to improve levels of transit service); and
4. Long-term rationing programs if the decline in fuel availability is too rapid for the other measures to keep pace.

At this point, almost nothing can be stated as fact concerning the impact on travel patterns of a long-term decline in the availability of fuel. The consumer will undoubtedly attempt to maintain maximum mobility within the limits of fuel availability. Traditional long-range planning has relied on past experience with growth and travel patterns to forecast future needs. Comparable data for planning under energy constraints are simply not available at this time. The results of contingency planning cannot merely be extended because the assumptions on elasticities may not be valid.

To meet the future need for long-range planning under energy constraints, the framework for such planning should be established now. A procedure to capture data on fuel allocation and consumption at a disaggregate level should be developed and a standardized measure of fuel availability determined. This information can be collected by each state, but federal coordination may be required to ensure consistency across all geographic areas.

A program to monitor trends in consumer behavior and in the public perception of the pending decline in the availability of fuel should also be initiated. Regional attitudinal surveys could help to determine public perception of the future availability of fuel. These perceptions should then be correlated with consumer behavior patterns as a guide to potential future modifications of behavior. For example, changes in automobile-buying behavior or in mode choice related to consumer attitudes on energy might reflect public perception of the energy future.

CONCLUSIONS

The urban transportation planning process will require some changes to adequately reflect the impact of fuel availability. The impact of the oil embargo of 1973 and 1974 has given rise to a new planning tool—the urban transportation energy contingency plan. The problems that were encountered during the shortage and the possibility of a reoccurrence suggest that such plans should be developed for every major metropolitan area. These contingency plans should describe policy options and realistically assess the energy conservation potential of each individual policy and policies in combination. These should be comprehensive, regional, multimodal action plans that can be easily implemented in an emergency.

The basis for long-term planning needs reevaluation. Current 20-year plans based on past trends in growth and travel may not be valid. The information obtained from the impacts of the oil embargo does not appear to be of much value in updating these plans. The planning process must be redefined to include the effects of long-term limitations on the availability of fuel as this information becomes available. The framework for capturing the necessary data should be established now. Future long-range plans will need to be reevaluated and updated periodically so that new information on behavioral patterns and policy impacts can be integrated. It may prove to be more beneficial to develop mid-range (5- to 10-year) plans that can be updated easily as more information becomes available.

A standardized definition of fuel availability and a method for capturing data on fuel allocation and consumption at a disaggregate level need to be established. This information should be coordinated with data on long-term public perceptions of, and reactions to, the future transportation-related energy environment.

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Redevelopment of a Comprehensive Approach to Urban Transportation Planning

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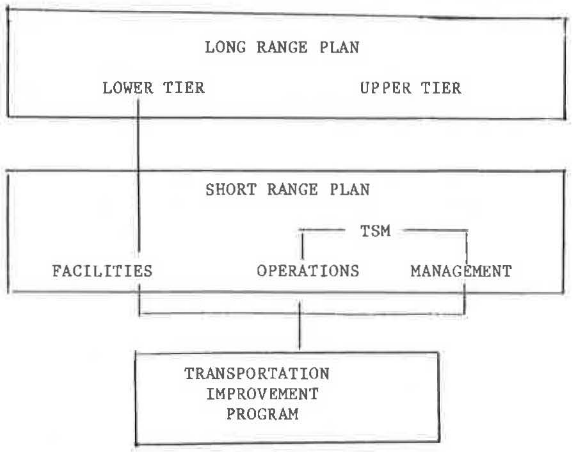
An attempt is described that is under way in southeastern Wisconsin to convert the conventional urban transportation planning process into a more problem-centered planning process, one that considers and integrates short-range and long-range considerations and comprehensively examines alternative facility and systems management solutions. The key to this improved planning process is the use of a new short-range transportation system plan in place of the conventional short-range transportation systems management plan. The new plan would be aimed at existing and short-range problems. Alternative solutions to be considered would include management and operational actions as well as facility improvements as staged and recommended in the long-range plan. The recommendations of the short-range plan should be appropriate for direct inclusion in the transportation improvement program. The short-range transportation planning process and its relation to long-range transportation planning, the steps that have been taken to apply the process, and some of the general principles used in developing the new short-range plan are discussed.

Urban transportation planning has undergone radical change in the past 10 years. Witness the list of acronyms of newly required or increasingly regulated urban transportation planning documents: TSM, TIP, LRP, AA, EIS, and TDP. Some believe these changes have led to necessarily fragmented urban transportation planning. The urban transportation planning process that has evolved is most commonly composed of a number of planning elements, each of which is largely considered separately from, and is not strongly related to,

Figure 1. Place of conventional transportation planning elements in the short-range planning process.



the other. The two principal elements of the most common urban transportation planning process are the long-range plan (LRP), which usually focuses on future problems and needs and alternative facility solutions, and a transportation system management (TSM) plan, which examines existing and short-term problems and needs and potential managerial and operational improvements.

A strong need would appear to exist for the urban transportation planning process to consider and interrelate existing, short-range, middle-range, and long-range transportation problems and needs and evaluate together and without bias their alternative facility and systems management solutions. Such a planning process is problem centered, recognizes short-range and long-range considerations and their interrelations, and considers artificial the distinction between planning for transportation system management and planning for facility improvement and expansion because in the proposed planning process both are considered jointly and equally as alternative solutions of largely the same problems.

This paper describes how such an overall (problem-centered), comprehensive (facility and management), integrated (short-range and long-range) urban transportation planning process is being considered in southeastern Wisconsin by the Southeastern Wisconsin Regional Planning Commission (SEWRPC). The process would be based primarily on the two common planning elements—a long-range plan and a short-range plan.

Consideration of the concept of a new planning process occurred when SEWRPC completed its first formal TSM plan (1). That first-generation plan contained recommendations for immediate and short-term TSM project implementation, outlined an agenda of more detailed planning to be undertaken for a few of the most promising and yet uncertain TSM improvements, and provided a design for a comprehensive, integrated, and overall short-range planning process to be undertaken for the second-generation TSM plan.

This paper summarizes the proposal for such a short-range planning element and includes a discussion of the general principles that were established for the design of the planning process, the basic elements that compose the planning process, and the relation of the proposed planning process to conventional long-range and TSM planning elements.

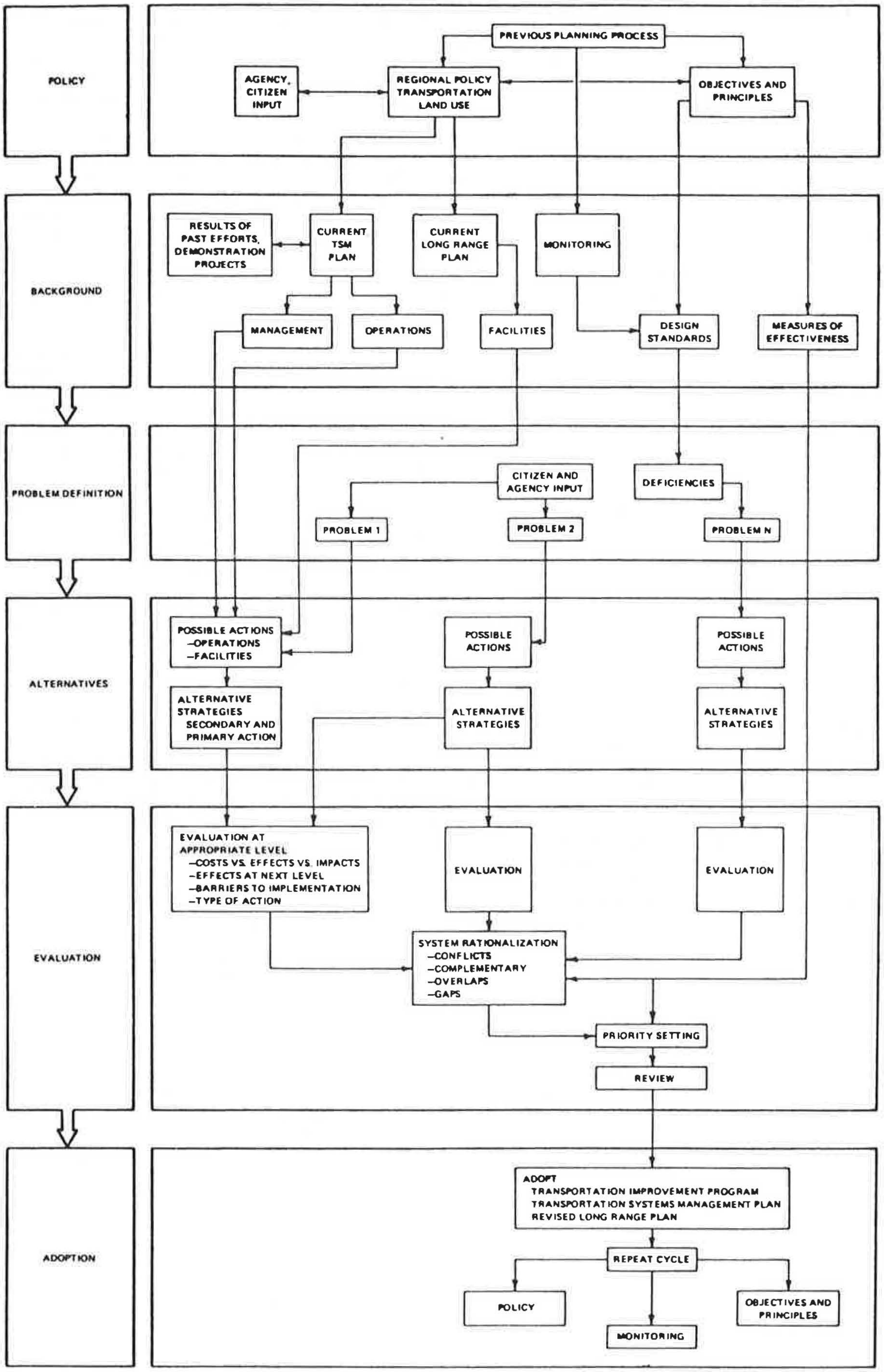
RELATION BETWEEN SHORT-RANGE AND CONVENTIONAL PLANNING ELEMENTS

The proposed short-range planning process is closely related to the common LRP and TSM planning elements. As Figure 1 shows, the proposed short-range planning process in essence combines TSM planning (by considering TSM alternatives to short-term problems) with short-range facility planning (by simultaneously considering staged facility alternatives from the LRP to the same problems). The LRP element serves as an input to the process, and the results of the process in turn provide for the possible advancing or delaying of the implementation recommendations of the LRP, thereby establishing a link between the long-range considerations of the LRP and short-range considerations and problems. The conventional TSM plan element can be viewed as some subset of the short-range planning process because conventional short-range TSM alternatives are part of the new short-range process and, in fact, a TSM plan could be abstracted from the short-range planning process recommendations. In addition, the recommendations of the short-range planning process more than those of any other planning process can be viewed as being capable of flowing directly to the transportation improvement program. This is because long- and short-term considerations would be included in the planning process and all competing alternatives—management, operations, facilities, and services—would be evaluated for their relative effectiveness.

The concept of the long-range plan, as developed and recently refined by SEWRPC in its just-completed long-range plan update, is uniquely suited to the development of an overall short-range planning process (see Figure 2). The new long-range plan of SEWRPC explicitly considers long-range and middle- to short-range needs as well as the uncertainty of those needs and their potential solutions by preparing the long-range transportation plan in two tiers of recommendations, an upper tier and a lower tier. Facilities placed in the lower tier of the plan are considered necessary to meet middle- and long-range needs and are recommended for short- or middle-term implementation as staged in the plan. Facilities placed in the upper tier remain in the long-range plan, but no further work is to be undertaken on their construction for a period of at least a decade. Facilities can be placed in the upper tier for a variety of reasons, including (a) a need that is only long term in nature, (b) uncertainty of need, (c) high cost or potentially significant impacts, and (d) current division of technical or public opinion. The concept of the two-tier long-range plan at SEWRPC, however, goes beyond that of separating the facility recommendations of a long-range plan on the basis of immediacy and certainty of need. The plan explicitly recognizes the potential of working over the short term to address certain transportation problems and deficiencies and thereby possibly reducing the need for planned upper-tier facilities. This is accomplished in the plan by recommending that, during the decade for which the implementation of upper-tier facilities is to be delayed, a combination of a small number of promising TSM measures be implemented to address the problems that the upper-tier facilities were to meet.

The SEWRPC two-tier plan envisioned that, if at some future time it was determined that the TSM actions along with lower-tier facility recommendations had been effective in adequately accommodating travel demand, steps could be taken at that time to formally remove the upper-tier proposals from the long-range plan. On the other hand, if the consensus at such a future time was

Figure 2. Short-range transportation planning process.



that such efforts had not adequately provided the needed transportation service, work could again proceed toward the construction of the proposed upper-tier facilities. In the meantime, the plan recommended that all right-of-way already cleared for upper-tier proposals be held in a transportation land bank and that appropriate consideration be given to the use of the land for parks and open space. The plan also recommended that any currently undeveloped lands needed to accommodate construction of the upper tier of the plan continue to be held in open use.

The short-range planning element to be discussed in this paper is intended to fit together well with this concept of a long-range transportation system plan. First, the short-range plan would serve to expand on consideration in the long-range plan of TSM actions that are intended to eliminate, if possible, the need for upper-tier facilities recommended in the long-range plan that should or should not be considered as facility alternatives in the short-range plan.

BASIC PRINCIPLES FOR THE SHORT-RANGE PLANNING PROCESS

The initial step in the development of a new short-range planning process at SEWRPC was to establish a set of basic principles to be used to describe in general terms what should be the characteristics of a new short-range transportation planning process. The basic principles established for development of a short-range plan were the following:

1. The planning process should focus on decision making, have as its general purpose the provision of highly relevant information for the careful consideration of alternatives, and lead to a selection of a proper course of action for various time frames.
2. The proposed transportation plan should constitute an integrated system. It is not possible through the analysis of individual actions alone to ensure such a system; rather, it is essential to examine how the individual actions interact and fit together into an integrated system.
3. The planning process must consider land-use activities as well as transportation. The interaction between land use and transportation is well known and should be explicitly considered. As far as possible, transportation actions should be used to complement land-use development and redevelopment plans that relate specifically to the needs of the region and of the individual communities that constitute the region.
4. The planning process needs to be concerned not only with end states but also with the steps necessary to reach end states. There is a need to consider the entire time span between the present and the long-range future. Thus, there should be a concern about the sequence in which projects are implemented and their staging. Furthermore, it should be recognized that the transportation planning process is an iterative process that alternates between systems-level and project-level planning. Thus, the output of a planning effort at one level will serve as input to the next cycle of planning activities at the other level.
5. The planning process should provide a well-working transportation system at all points in time. Although certain improvements can be expected to effectively solve transportation problems over the long term, there is a need to consider a wide range of interim measures that deal with problems over the short term.
6. The planning process should deal specifically with the uncertainty associated with the implementation of plans. Uncertainty exists in future energy supplies, growth patterns, funding, and public acceptance of proposed actions. These uncertainties should be explicitly dealt with in the planning process. The plans produced by the process should therefore be flexible and adaptive and recognize the feasibility problems that may be involved in implementing certain types of actions.
7. The options that should be considered in a short-range planning process should be based on specific statements of transportation objectives and relate directly to identified problems and deficiencies. These actions should not only involve changes in procedures and policies for the operation and management of the transportation system but should also, as necessary, include system expansion and new technologies that are consistent with the long-range plan. Furthermore, there should be room in the process for experimentation and demonstration of innovative as well as conventional options.
8. In developing a short-range plan that considers facilities as well as operational and managerial improvements, a fundamental principle that should be followed is that major investments in new facilities will take place only after it has been demonstrated that operational improvements have not or cannot provide an acceptable quality of service or have failed to adequately address transportation problems and deficiencies. The facility options considered must be recommended in the lower tier of the long-range plan.
9. Evaluation of options should relate to the particular level at which they function. Options such as carpooling, transit information services, and rescheduling of work times affect an entire urbanized area. Other options, such as intersection redesign and transit shelters, have a primary effect on a limited local area. Other options may have primary effects at the level of the urbanized subarea, the freeway corridor, the arterial corridor, or the region. Each option should be primarily evaluated only at the level at which it has its major effect (in comparison with other options at the same level) and at the next higher level to check for system consistency. Some examples of TSM strategies and their level of primary effect are given in the table below.

Level	Strategy
Region	Freeway projects
	Intercity and suburban transit service
	Major regulatory changes
Urbanized area	Areawide ride-sharing programs
	Transit marketing
	Transit information services
	Work rescheduling
	Congestion pricing
	Transit fare policies
	Improved transit management
Urbanized subarea	Computerized signals
	Changes in parking pricing policy
	Regulation of parking supply
	Restriction of trucks
	Automobile-restricted zones
Freeway corridor	Centralized freeway operational control
	Priority lanes for high-occupancy vehicles
	Park-and-ride facilities
	Reversible lanes
	Safety improvements
Arterial corridor	Bus lanes and streets
	Signal preemption by buses
	Removal of on-street parking
	One-way streets
	Transit service improvements
	Safety improvements
Local and spot improvements	Improved signalization
	Transit shelters
	Channelization

10. Certain objectives and measures of effectiveness may conflict and require resolution through compromise. Meaningful plan evaluation can only take place through a comprehensive analysis of each of the alternatives in relation to measures of effectiveness. Criteria for evaluation should include measures of changes in mobility, impact, and costs, and the evaluation process should identify the trade-offs between these factors in the selection of a course of action.

11. Finally, the transportation planning process should provide a forum for constructive debate on the shape and form of the transportation system. Such a debate should be structured so as to lead to decisions that recognize the diverse interests of the residents of the region.

SHORT-RANGE TRANSPORTATION PLANNING PROCESS

A new short-range transportation planning process was proposed within the framework of the basic principles. As Figure 2 shows, the planning process is built around the identification of existing and short-range transportation problems and the assessment of alternative solutions to these problems. The definition of short-range problems and deficiencies is viewed as proceeding from the inventories, analyses, and findings of recent planning efforts and the assessment of currently monitored transportation system performance with respect to attainment of the adopted regional transportation system objectives. Alternative managerial, operational, and facility improvements would then be examined as potential solutions to problems. These alternative actions would be taken from the lower-tier recommendations of the long-range plan or would be newly developed and proposed. After the evaluation of alternative actions and the preliminary selection of actions that are appropriate in response to particular problems, these actions would be combined into a rational regional system.

The planning process is slightly different from the conventional type in that it is intended to be a continuous process composed of a number of studies that involve different problem-solving activities. These studies could be going on at the same time, but they would begin and end at different times (see Figure 3). It can be expected that certain problems will have obvious solutions or a limited number of solutions that can be easily assessed and implemented whereas other problems will require lengthy and complex analyses. Each study would have its own evaluation of alternative strategies, recommendations for implementation, and an evaluation of consistency with other transportation plans, principally the long-range plan. As the results of various short-range studies became known, they would be incorporated in the short-range plan and, if appropriate, in the long-range plan. It is expected that the short-range plan would be updated annually and principally include the necessary rationalization of the transportation system, a review of planning objectives, and a redefinition of existing and short-range transportation problems. Alternative solutions to these problems can be investigated in this annual update of the short-range plan, or new studies can be recommended to deal with these problems. The seven major steps in the short-range planning process, which is applicable to the annual plan update and the separate studies it may recommend, are described below.

Formulation of Transportation System Objectives

One of the most critical phases of a planning process is to develop explicit statements of objectives. These statements must relate to both transportation and land use. Their primary purpose should be to establish some basic ground rules and guidance for development and choice in the short-range plan. Design standards and measures of effectiveness would be developed to measure quantitatively the attainment of each objective formulated. Design standards would specify minimum or desirable levels of performance and impacts of the transportation system and would principally be used for problem definition, whereas measures of effectiveness would only specify the detailed criteria that represent each objective quantitatively and would be used in the evaluation of alternative problem solutions.

Transportation planning is a cyclic and iterative process, and it is important that the findings and recommendations of previous studies be used as a point of departure for subsequent planning, particularly with respect to the development of planning objectives. Objectives and standards that have been developed in previous long-range planning efforts, however, may have to be modified for the purposes of short-range planning. These modifications should lead to objectives that are more specific in their measurement of effects on local areas and also helpful in the evaluation of operational and managerial options. The development of objectives should involve interaction with, and review by, other planning and implementing agencies, concerned public officials, and private citizens.

Background Information and Inventory

The next step in the process is to compile information on previous planning efforts and the current level of system performance as input to developing a short-range transportation plan. These previous efforts would include the current TSM or short-range plan and its recommended operational and management improvements and the current long-range plan, which would include both facilities and operational improvements. Other background information and inventories would include the results of other past planning efforts, demonstration projects, and all system-monitoring information.

Problem Definition

Problem definition follows the compilation of background information and inventories. There are two basic sources of statements of problem definition. The first of these would be other planning and implementing agencies and possibly private citizens; the second would be deficiencies identified in analysis of system-monitoring information. A large number of problems may be identified at this stage. These statements would then be categorized by level—regional, urbanized area, subarea, corridor, or spot—and then combined to ensure a minimum amount of overlap. A decision would then be made as to whether each problem would be analyzed—that is, whether alternative solutions would be generated and evaluated and the best alternative selected—in the annual update of the short-range plan or in a separate study.

Preparation of Alternative Solutions

The next step in each short-range planning effort would be to identify a series of alternative actions that relate

Figure 3. Timing of activities in the short-range planning process.

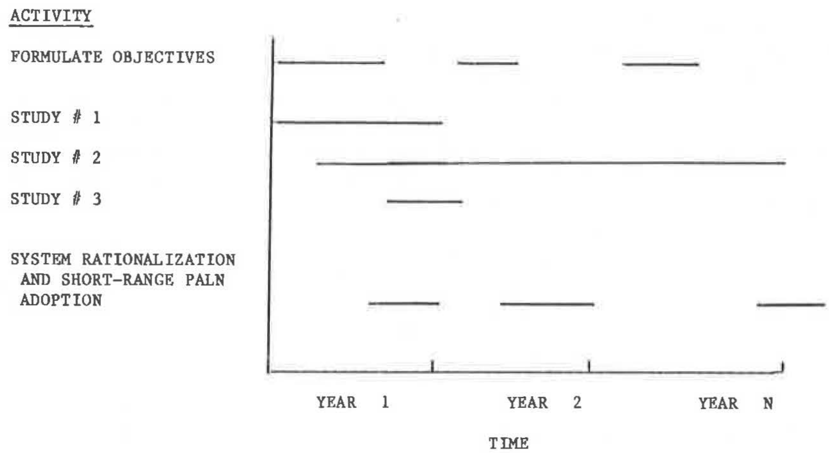


Table 1. Techniques for evaluating alternatives at various project levels.

Impact	Technique	Project Level Region	Urbanized Area	Urbanized Subarea	Freeway Corridor	Arterial Corridor	Local
Cost	Statistical cost estimates	*	*	*	*		
	Engineering cost estimates			*	*	*	*
Feasibility and design	Technical feasibility	*	*	*	*	*	*
	Technical design	*	*	*	*	*	*
Environment	Environmental impact statement	*	+	+	+	-	
	Negative declaration		-	+	+	*	-
	Not a major action				-	+	*
Community	Advisory committee	*	*	+	-	-	-
	Public hearing information meeting	*	*	+	+	-	-
Mobility	Regional simulation	*	*				
	Focusing		-	+	*		
	Windowing			+		*	
	Microassignment				+	+	+
	Capacity analysis						*
	Indirect effects		+				

Note: * = most likely; + = likely; - = possible.

to the solution of the identified problems. These actions would be derived from the long-range plan or would involve the generation of new TSM improvements, including managerial and operational actions. The alternatives examined could be combined into alternative strategies for dealing with the problems.

Evaluation of Alternative Solutions

Each alternative action and strategy would then be evaluated at the level at which the problem has been identified and at the next higher level as a check for transportation system consistency. Evaluation would be based on examining each alternative's attainment of defined planning objectives by comparing their "scores" on measures of effectiveness for each objective. The evaluation could be structured in a cost-effectiveness framework to highlight the trade-offs between alternative actions, costs, impacts, and mobility. The gains in mobility achieved at the expense of additional negative impacts and costs would be explicitly defined through such an analysis.

It can be expected that different evaluation procedures and measures would be used at different levels of evaluation. For example, an evaluation of environmental effects at a spot or corridor level may require the appropriate implementing agency to prepare an environmental impact statement. Table 1 gives the types of techniques that are currently available for evaluation of alternatives at the different levels. Each of these techniques would quantify measures of performance of alternative actions as defined from the agreed-on planning objectives and standards.

The evaluation process could also produce information on the sequence of steps that should be used to deal with a particular problem. It can be postulated that low-capital improvements in the operation or management of a transportation facility or service should be implemented before major capital investment is made in new or improved facilities. Only after it has been demonstrated that these improvements cannot solve the problems toward which they have been directed should the alternative new or improved facility solutions be implemented. This type of transportation investment policy—that is, ensuring that existing transportation facilities and services operate at their maximum efficiency before any extensive new capital investment is undertaken—could be supported by the proposed short-range planning process. In addition, the sequential implementation of alternative system management or operational strategies could be considered in this planning process.

System Rationalization

After the evaluation of alternative actions and strategies in relation to individual problem statements, the next step is system rationalization. The purpose of this effort would be to ensure that the individual actions recommended for each problem fit together to form a cohesive, rational, and efficient transportation system. Actions can be identified as independent (those that can be combined with any other actions because they do not interact), complementary (those that can be grouped with other actions in a positive way), or conflicting (those that involve a choice between competing projects). The process of system rationalization would involve the identification of actions by type and the subsequent packaging of actions into a logical system.

Adoption of Plan

The final phase of the process would be adoption of the plan and movement toward implementation. Actions recommended in the planning process should be included in the transportation improvement program.

SUMMARY AND CONCLUSIONS

The revised urban transportation planning process proposed in this paper is intended to better consider and interrelate existing, short-range, middle-range, and long-range transportation needs. In addition, the process is intended to be more unbiased and comprehensive than the conventional planning process because it would consider both systems management and facility improvements as alternatives to short- and long-range problems. Because the facility alternatives considered in the short-range planning process will be those that have been recommended in the long-range plan, an explicit link between short- and long-range planning will be established. It is hoped that this link will allow short-range plan recommendations to provide the sole coordinated planning input into the transportation improvement program. The drawback to this approach is that certain facilities that are necessary to meet long-range needs will not be advanced for implementation until they are also the most appropriate alternative for short-range needs.

This revised transportation planning process has been proposed and is now being considered for implementation in southeastern Wisconsin. It has been partially implemented in that a number of studies have been initiated to examine specific transportation problems and the first annual update of the TSM plan for the region has been completed. Among the studies under way is a subarea study that focuses on alternative TSM actions and facility improvements that can be made in an area where long-planned freeways have been removed from the long-range plan. Another study will examine the benefits and costs of freeway operational control in the Milwaukee area in response to freeway congestion. An effort is also under way to coordinate and promote studies of facility improvements at the "stub ends" of all uncompleted freeways in Milwaukee County. The purpose of these proposed stub-end improvements is to provide better freeway connections to surface arterials, better utilization of existing freeway facilities, and a reduction in congestion and other negative impacts in neighborhoods adjacent to the stub ends of freeways. In addition to these studies, others are now being conducted that point toward improvement in taxicab and transit service in the Milwaukee area and better operation of streets and highways through analysis of major arterial corridors.

ACKNOWLEDGMENT

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REFERENCE

1. A Transportation Systems Management Plan for the Kenosha, Milwaukee and Racine Urbanized Areas in Southeastern Wisconsin. Southeastern Wisconsin Regional Planning Commission, Waukesha, Community Assistance Planning Rept. 21, Dec. 1977.

Long-Range Transportation Planning in Southeastern Wisconsin

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The evolution of long-range transportation system planning at one planning agency, the Southeastern Wisconsin Regional Planning Commission (SEWRPC), is examined. Some conclusions about the continued role of long-range planning are drawn, and some directions for further evolution of such planning are suggested. After a brief historical review of long-range transportation system planning at SEWRPC, five recent criticisms of the planning process in southeastern Wisconsin and elsewhere are identified: (a) the need for short-range emphasis; (b) an inability to deal with uncertainty; (c) disregard of fiscal constraints; (d) excessive orientation toward facilities; and (e) neglect of local plan impacts. The eight fundamental principles of transportation planning used by SEWRPC are reviewed in light of these criticisms. Although they are found to be basically sound, they are shown to require expansion to (a) include a provision for subregional planning, (b) deal with uncertainty and explain the approach taken by SEWRPC and a possible method that is under development, (c) alter the planning process to consider all alternatives including system operation and management initiatives, and (d) develop an integrated transportation planning process that effectively brings together long-range and short-range transportation system planning and programming.

In the three or more years since the publication of the joint regulations on transportation improvement programming (TIP) and transportation system management (TSM) planning (1), probably no single conceptual issue has, or perhaps should have, occupied the attention of the transportation planning profession as has the proper continuing role (if any) of long-range transportation system planning. Yet, as metropolitan planning organizations (MPOs) across the country attempt to work out their individual responses to this issue, one thing is clear: The development of the role of long-range planning is and will continue to be an evolutionary, not revolutionary, process. The purpose of this paper is to examine this process from the perspective of a single regional planning agency—the Southeastern Wisconsin Regional Planning Commission (SEWRPC)—to draw some conclusions about the continued role of long-range transportation system planning, and to suggest some possible directions for the further evolution of long-range transportation system planning.

TRANSPORTATION PLANNING AT SEWRPC

SEWRPC was created in 1960 as a voluntary advisory body to assist in cooperative planning for the orderly development of a seven-county region in southeastern Wisconsin that includes the Kenosha, Milwaukee, and Racine urbanized areas. The first major work program of the commission directed toward the preparation of a framework of advisory plans for the physical development of the region was a study of regional land use and transportation. In December 1966, SEWRPC adopted a regional land-use plan and a regional transportation (highway and transit) plan. The regional transportation plan, which had a design year of 1990, recommended construction of an extensive freeway system and implementation of a modified rapid transit system in which motor buses would operate in mixed traffic on freeways and, in corridors where it was warranted by freeway congestion, on exclusive bus transit ways.

In the late 1960s and early 1970s, SEWRPC devoted its attention to refinement and implementation of the plan. It worked with the state government and local governments to develop detailed functional and jurisdictional highway plans for each county in the region, prepared or assisted in the preparation of transit development programs for each of the three urbanized areas, and helped to develop a detailed plan for the modified rapid transit system in Milwaukee, all within the framework provided by the adopted transportation system plan.

Meanwhile, a number of significant developments occurred in the region on other fronts. Every freeway and major parkway recommended in the 1966 regional transportation plan was put into the preliminary engineering phase, at least to the extent of locating centerlines and preparing large-scale preliminary plans. Thus, projects were no longer lines on a map. Major segments of the regional freeway system, on which construction had begun in the late 1950s and early 1960s, were completed and opened to traffic, and right-of-way acquisition and final engineering proceeded for other major segments. But substantial opposition arose to the completion of all major uncompleted freeway segments in Milwaukee County, and this resulted in public protests and lawsuits against individual freeway projects. Eventually, some local and state legislators were elected who were opposed to further freeway construction and, ultimately, a countywide antifreeway movement emerged that brought virtually all freeway construction and right-of-way acquisition in the county to a halt.

Thus, in the mid-1970s, as SEWRPC proceeded to develop and evaluate alternative plans as part of the first major review, reevaluation, and revision of the regional land-use and transportation plans, it found itself caught in the middle of a great public controversy. On one side stood the freeway proponents, including business and labor, and on the other the freeway opponents, including most neighborhood groups.

OBJECTIONS TO THE LONG-RANGE PLANNING PROCESS

The importance of this controversy is that, in questioning the substance of the long-range planning work of SEWRPC, freeway opponents also attacked the validity of the long-range planning process. The arguments used, many of which were also used across the country in both similar and different contexts, include five major points:

1. The need for short-range emphasis—It was agreed that cities are currently confronted with innumerable problems, in transportation and other areas, that call for immediate solutions. Elected officials and the general public are principally interested in the short range. Federal regulations on TIP and TSM seem to reinforce this need for a short-range emphasis. Given this short-range emphasis, what is the utility of long-range transportation system planning?
2. The inability to deal with uncertainty—Long-range plans have to be based on long-range forecasts of important regional characteristics, such as population size and distribution, economic activity size and distribution, and land use, and on assumptions of other critical factors of the future environment, such as the state of the art of technology, the price and availability of energy, the nature of regulatory constraints, and general social attitudes and behavior. Given the great uncertainty in these forecasts and assumptions—an uncertainty that was brought to public attention by the generally unanticipated major changes in population growth and the energy situation in the late 1960s and early 1970s—what is the validity of long-range transportation system planning?
3. Disregard of fiscal constraints—In many cities, there is an immediate and apparently a long-term chronic shortage of available funds for basic urban services, including transportation. People contend that long-range transportation system plans are not sufficiently sensitive to this problem.
4. Excessive orientation to facilities—It was perceived that long-range transportation system plans emphasized the construction of facilities as a solution to transportation problems and did not give sufficient consideration to potentially useful initiatives in system management and operation. This view was reinforced by the TIP and TSM regulations.
5. Neglect of local plan impacts—Long-range transportation system plans prepared at the regional level could not deal in great detail with impacts of plan recommendations at the community and neighborhood levels. Many people considered this to be a fatal flaw in the long-range planning process.

PRINCIPLES OF TRANSPORTATION PLANNING

In 1965, Bauer (2) identified eight fundamental principles of transportation planning that were used by SEWRPC in the preparation of its initial land-use and transportation plans:

1. Transportation planning must be areawide or regional in scope.
2. Transportation planning must be conducted concurrently with, and cannot be separated from, land-use planning.
3. Not only must transportation planning be conducted concurrently with land-use planning but also transportation system plans must be based on long-range areawide land-use plans.
4. Highway and transit systems must be planned together.
5. Transportation facilities must be planned as an integrated system.
6. Both land-use and transportation plans must recognize the existence of a limited base of natural resources.

7. The land-use and transportation planning process must be based on community development objectives.

8. The land-use and transportation planning process must scale plans against the financial resources of the community and against the legal authority available for plan implementation.

During the past three years, confronted with the criticisms of its long-range transportation planning process, SEWRPC has undertaken the reevaluation of its long-range transportation system plans and its initial transportation system management plan and preparation of a transportation planning work program for the late 1970s and early 1980s. Through these efforts, SEWRPC was able to reexamine the validity of Bauer's eight benchmark principles. Most were confirmed to be valid. Some required elaboration or amplification in light of changing values. But their basic soundness was substantiated. They now stand as guideposts for SEWRPC in the continuing evolution of its transportation planning process, and as such they may be valuable to other planning agencies that are struggling with the same or similar problems.

REEXAMINATION OF THE PRINCIPLES OF LONG-RANGE PLANNING

The first conclusion reached by SEWRPC in its reexamination of the validity of the principles of long-range planning was that long-range planning itself was, is, and increasingly will be a valuable and useful process. It was recognized that many of the impacts of long-range plan recommendations that led some people to criticize both the plans and the process that produced them, such as the dislocation caused by urban freeway construction, were in fact not the product of long-range planning but the direct result of a lack of long-range planning earlier in the region's history. It is clear that decisions on the disposition of nonrenewable natural resources—the most important of which is land—and on the overall development pattern of an urban area can only be made in a long-term context. Similarly, commitments to implementation of new fixed-facility systems or major expansions of existing systems can also only be made through a long-range plan. Finally, implementation of difficult major changes in societal attitudes, such as use of the automobile, use of transit, and ride sharing, need to be at least addressed on a long-range basis. Although long-range planning has historically been an early and attractive target for budget cutters during times of apparent scarcity or retrenchment, it is at such times that long-range planning is of most value if for no other reason than that long-range planning identifies those options that are left open and those that are foreclosed by specific courses of action. Highly desirable alternatives have been thoughtlessly foreclosed in the past without such planning, an unfortunate occurrence that would undoubtedly happen again. SEWRPC and its staff was convinced, therefore, of the continuing and ever-growing importance and validity of long-range planning as they reconsidered the eight planning principles.

Scope of Transportation Planning

SEWRPC had always conceived of planning as a cyclic process. Under this concept, it is recognized that it is quite difficult at the system planning level to identify and consider all of the costs and other effects of implementing a proposed transportation facility or service. Thus, although the first iteration of system planning does the best possible job of identifying and considering the costs and other impacts of system alternatives, it has always been understood that detailed project-level planning would result in better information on project costs and impacts and, more importantly, in the testing of public reaction to and acceptance of proposed projects. If plan elements that were judged to be desirable at the system level were found to be unacceptable at the project level, this would be carefully considered in the next cycle of system planning and alternatives to the objectionable plan elements would be sought. However, although in theory the cyclic notion of planning functions to reconcile regional plans and subregional impacts, in practice the project development process has become so lengthy (because of so-called "action plans" and environmental assessment processes, among other things) that the cyclic notion of planning, although still valid, has not resulted in the timely feedback of project-level data to the regional level.

Wachs and others (3), Hansen and Lockwood (4), and others have identified the need for a less-than-regional component to the transportation planning process. In the conception of SEWRPC, a relatively short but intensive subregional transportation planning process would be pursued in carefully selected portions of the region, at first primarily in those areas where controversy had developed over previous plan recommendations. Thus, a subregional planning process could identify community- and neighborhood-level impacts of plan elements and test the acceptability of alternative proposals.

SEWRPC is currently mounting such a major subregional transportation planning study in an area of northwest Milwaukee County and north-suburban Ozaukee County, an area where controversy over two planned freeway segments led SEWRPC to delete the freeways from the plan in late 1977. The study, which includes a heavy component of public involvement, is being carried out as a highly cooperative effort in which substantial technical staff and resources are being provided by the Wisconsin Department of Transportation, Milwaukee and Ozaukee Counties, the Milwaukee County Transit System, and the city of Milwaukee in addition to SEWRPC itself.

The major remaining conceptual hurdle is the problematical task of reconciling regional perspectives, which tend to be long-range, and subregional perspectives, which tend to be more immediate, and arriving at a true system plan that serves the needs of both the subregion and the region and addresses both short- and long-range needs. Hansen and Lockwood (4) and Schulz and others (5) are among those who have suggested that this problem can be solved by cycling so quickly and frequently between the regional and subregional levels that, in effect, regional and subregional planning processes are being pursued simultaneously. If we assume that this approach will be successful, the first of Bauer's basic principles can be expanded: Transportation planning must be areawide or regional in scope, but it must be a cyclic process that considers both region-level and community- and neighborhood-level impacts of plan elements through a series of successive iterations of regional and subregional planning efforts.

Transportation Planning and Land-Use Planning

If anything, the underlying soundness of the notion that transportation planning must be conducted concurrently with, and cannot be separated from, land-use planning has become more accepted over time.

Long-Range Areawide Land-Use Plans as Basis of Transportation System Plans

It is in the principle that transportation system plans must be based on long-range areawide land-use plans that the problem of uncertainty arises. The idea underlying this principle is that the SEWRPC planning process is partially normative and partially accommodative. It is normative in that it produces land-use and transportation plans that provide direction to the region and, in a sense, represent a future seen as desirable by SEWRPC. It is accommodative in that the plans prescribe a set of actions by which the region can accommodate itself to a future expected by SEWRPC. The normative nature of the process is particularly evident in SEWRPC's historic use of a land-use plan, as opposed to a land-use projection, as a basis on which the transportation plan is constructed. A normative land-use plan is developed that reflects a sound pattern of development and land use based on forecasts of population and economic activity. Transportation plan alternatives are then developed to accommodate the travel demand that is forecast to result from the land-use plan, and the "best" alternative in terms of meeting the demand and satisfying the other transportation plan objectives and standards is chosen. Thus, the transportation plan is designed to be supportive of the desired land-use plan.

Although in practice this approach has been generally successful in the region, it is subject to a number of pitfalls:

1. The selected transportation plan may not be completely or exactly implemented.
2. The supporting public water supply, sewers, parks and open space, housing, and other public utility and service plans, which together with the land-use and transportation plans make up the comprehensive physical development plan for the region and, like the transportation plan, are based on the land-use plan, may not themselves be completely or exactly implemented.
3. The provision of public facilities and services such as highways, transit, and sanitary sewers is not the sole, or in many cases even the primary, determinant of the pattern of urban development. Land-use controls, life-style preference, and the operation of the urban land market represent other important factors.
4. Still other factors, many of which are external to and thus uncontrollable by the region—such as the price and availability of energy, the state of the national economy, the state of the art of technology, and the availability of federal and state financial assistance—affect land-use development and transportation needs. In short, there is considerable uncertainty inherent in land-use and transportation system development.

SEWRPC has developed what it believes is a pragmatic and interesting approach to this problem. In its recently completed reevaluation of the long-range regional transportation system plan (6), SEWRPC used a "two-tier" concept in dealing with controversial freeways in Milwaukee County. Those freeways that SEWRPC judged would not be needed and could not be implemented under most conceivable circumstances by the plan design year 2000 were deleted from the plan. Those freeways that it was judged would be needed in and could be implemented by the year 2000 under most conceivable circumstances were included in the "lower" tier of the plan and recommended for immediate implementation. Those freeways that SEWRPC was uncertain would be needed in or could be implemented by the year 2000 were included in the "upper" tier of the plan, which meant that SEWRPC recommended that no further work be accomplished to construct these freeways for a period of at least 10 years, until the next plan reevaluation, but also that nothing be done during that period to preclude their implementation, such as infilling of cleared freeway corridors or development of undeveloped freeway corridors. Cleared or undeveloped land would be held as recreational open space in a transportation land bank. In the meantime, a variety of TSM-type actions—including, among others, areawide freeway ramp metering with preferential access for high-occupancy vehicles, carpooling and vanpooling, improved transit service, traffic signing and signalization, parking prohibitions, selected arterial improvements, and work-time rescheduling—are recommended in an effort to improve the efficiency of the existing transportation system and to manage and possibly reduce peak travel demands on that system. At the next plan reevaluation, the upper-tier freeways could be moved to the lower tier if the TSM actions are unsuccessful, deleted from the plan if they are successful, or left in the upper tier if uncertainty remains.

Recently, SEWRPC received preliminary approval from the Urban Mass Transportation Administration (UMTA) to extend, refine, and apply the two-tier concept to transit in the Milwaukee urbanized area through an areawide alternatives analysis that incorporates an "alternative futures" planning technique. Alternative futures planning has been discussed in the literature by Pollock (7), the Chicago Area Transportation Study (8), Schulz and others (5), and Bernard (9), among others. In this application, two scenarios would be developed that are intentionally relatively extreme and consist of linked forecasts of regional population and employment and important external environmental factors such as the price and availability of transportation energy, life-style, technology, and the availability of federal, state, and local transportation financing. For each scenario, a centralized land-use plan that represents a normative future with a relatively high degree of success in shaping urban development and a decentralized land-use plan that represents an accommodative future with a relatively low degree of success in shaping development would be prepared. For each of these four alternative futures, the best transit system plan for the region would be determined through a sketch-planning process.

Fixed-guideway plan elements that appear in all or most of the best alternative future transportation plans (if any) would nominally constitute a lower-tier fixed-guideway plan subject to an intensive process of system rationalization to ensure a connective, functioning system that is consistent with the guidelines of the alternatives analysis and would be recommended for immediate progress toward implementation, again in a manner consistent with the process of alternatives analysis. Fixed-guideway plan elements that appear in at least one of the best alternative future transportation plans (if any) would nominally constitute an upper-tier fixed-guideway plan, again subject to system rationalization. Although upper-tier fixed-guideway elements would not be pushed toward implementation, it would be recommended that available or potentially available upper-tier fixed-guideway corridors (rail rights-of-way, portions of cleared freeway rights-of-way, or utility rights-of-way) be preserved for possible future fixed-guideway development, if necessary through acquisition and placement in the transportation land bank. It is the intention of SEWRPC to further pursue, expand, and apply the alternative futures planning process both in transportation and other functional planning areas.

Although researchers like Manheim and others (10) have suggested different methods such as structured contingency analysis for dealing with this uncertainty, the need to confront it is unquestioned. Thus, the third of Bauer's basic principles can be augmented as follows: Not only must transportation planning be conducted with land-use planning, but also transportation system plans must be based on long-range areawide land-use plans.

However, the transportation planning process must explicitly recognize and confront the uncertainty in both the implementation of that land-use plan and the underlying planning assumptions about important factors such as energy, technology, financing, and life-style.

Joint Planning of Highway and Transit Systems

The original SEWRPC transportation system plan adopted in 1966 contained four recommendations that would be categorized today as TSM: greatly improved transit service, express-bus use of uncongested freeways in mixed traffic, a reduction in the availability of parking in the Milwaukee central business district (CBD), and prohibition of peak-hour parking in the peak direction on congested arterial streets and highways. The year 2000 plan expands on these initiatives by recommending an areawide freeway ramp-metering system with preferential access for high-occupancy vehicles. The SEWRPC transportation system management plan (11) provides a comprehensive program of TSM actions for the region, and SEWRPC is currently embarked on a major integrated program of TSM implementation and further study.

Thus, the fourth of Bauer's principles can be amplified as follows: Highway and transit systems must be planned together, and all alternatives, including system operation and management and construction of facilities, must be considered.

Planning Transportation Facilities as an Integrated System

The notion that transportation facilities must be planned as an integrated system is unchallenged, but there is a need to expand its scope. Faced with transportation improvement programs, TSM plans, transportation plans for the elderly and the handicapped, long-range plans, alternatives analysis, and other related and unrelated transportation planning work, MPOs are threatened with the possibility that their resources and energies will be spent on a variety of competing tasks, and all to little effect, unless the various elements of programming and long-range and short-range planning can be integrated into a single transportation planning process. In another paper in this Record, Beimborn and others describe the integrated planning process being developed by SEWRPC.

Bauer's fifth principle can thus be stated as follows: Transportation facilities and services must be planned as an integrated system through a process that integrates programming and short-range and long-range planning.

Natural Resources

SEWRPC's past and present consideration of conservation and enhancement of the remaining natural-resource base in the region as a primary objective of all its planning efforts reflects the fact that the principle of recognition of the limited base of natural resources is unchallenged. It is interesting to note, however, two developments that have occurred since the principle was first articulated:

1. Many regional planning agencies, including SEWRPC, have become heavily involved in environmental planning, especially in areawide water quality management and air quality maintenance. Thus, the importance of environmental considerations in the long-range planning process, and the resultant need to carefully coordinate the various affected planning programs, have greatly increased.
2. Many people feel that the process for assessment of environmental impacts, as required by the National Environmental Policy Act of 1969 and especially as implemented since the passage of that landmark legislation, has served to undermine the role and effect of all planning, especially long-range planning. If an environmental impact assessment is indeed the basis for making a go/no-go decision on a project, then the local or regional plan that recommended that project as a plan element has less validity as a decision tool. SEWRPC is currently attempting to reconcile the unquestionable need for an environmental impact assessment with the role of the planning process. One possible approach is to prepare a system-level environmental impact assessment that can then serve as a structural framework for more detailed impact assessment work as a plan element or project progresses toward implementation. To this end, SEWRPC has prepared, as an appendix to its recently completed plan, a first attempt at such a system-level assessment. This issue remains, however, a vexing problem that will undoubtedly occupy considerable thought and energy in the future.

The Planning Process and Community Development Objectives

Bauer's principle that the land-use and transportation planning process must be based on community development objectives stands without need of amplification. However, the need to consider and balance, to the extent possible, both short-range values and long-range goals must be recognized.

Scaling Plans Against Community Financial Resources and Legal Authority for Implementation

During the years since adoption of the initial SEWRPC land-use and transportation plans and especially during the recent, sometimes painful, process of plan reevaluation, the overriding impression received by SEWRPC and its staff is one of fragmenting authority and responsibility. It is apparent that, in the last two decades of the twentieth century, the institutional structures of federal government, state government, local government, private sector, and citizenry and the intricate interinstitutional relations that control and influence the planning, implementation, management, and operation of major, complex urban service systems such as transportation or sewers may be inadequate to the task. That is, power is so fragmented and transitory in major urban areas that it is becoming ever more difficult to assemble and maintain the coalition of interests and institutions necessary to plan and then implement a major system. Widely differing symptoms of this problem are appearing. Two examples can be mentioned: (a) the UMTA emphasis on a free-standing, independent "usable segment" in implementing fixed-guideway transit systems and (b) the emerging "appropriate technology" movement. The implications of this development for planning processes based on systems engineering are not as yet entirely clear but are bound to be profound. Although this development requires no amendment to Bauer's eighth principle, it represents an important institutional constraint in future plan development, especially in long-range systems planning.

SUMMARY AND CONCLUSIONS

In southeastern Wisconsin as elsewhere in the United States, the long-range transportation system planning process was subjected to criticism during the late 1960s and 1970s. As this process continues to evolve, an examination of the underlying basic principles of the process indicates that they remain basically valid and require only some expansion to provide a technically sound and sensible basis for extending the evolutionary process of transportation system planning into the 1980s and beyond.

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Parametric Analysis: A Sketch-Planning Tool

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An analytical procedure to conduct sketch-planning analysis for exclusive transit facilities and its application in the Jacksonville, Florida, metropolitan area are described. Unlike detailed testing, in which the objective is to select a single recommended transportation scheme, the sketch-planning technique only screens alternatives to identify candidate transportation systems for more detailed testing. The method suggested for assessing the feasibility of rapid transit is termed parametric analysis and generally conforms to the transportation planning process currently used throughout the nation. Two major differences are that the parametric analysis is usually conducted at a larger-than-zonal scale and, instead of computing a single modal split, assumes various transit capture rates. In addition, each transit technology is specified in terms of performance parameters such as minimum headways, speeds, and unit costs. The consequences for patronage, revenue, and cost can be determined for each capture rate and test situation, and thus the feasibility of exclusive transit facilities can be assessed. Parametric analysis provides a useful, cost-effective procedure for conducting rapid transit sketch planning.

During the past two decades, the focus of most long-range transportation research and analysis has been on the detailed study of transportation alternatives. Because of the effort and cost involved in detailed testing of transportation networks, planners have been limited in the number of alternatives that could be considered. In response to this constraint, analytical techniques are needed that can inexpensively examine a large number of alternatives at a less detailed level. The intent of these procedures, which are termed sketch planning, is not to select a recommended plan but rather to identify promising alternatives that should be subjected to more detailed planning and to eliminate from further analysis those schemes that do not prove workable. The use of a two-tiered testing process (sketch planning and detailed) provides a cost-effective method for examining a wide range of alternatives and ultimately selecting a recommended transportation plan.

One such sketch-planning tool is the community aggregate planning model (CAPM), which has been successfully used in conducting analysis of highway alternatives. Unfortunately, transit analysis lacks a comparable, widely accepted planning tool.

This paper describes one such approach—a sketch-planning tool called parametric analysis—and its application to the testing of the feasibility of exclusive transit facilities and the desirability of various regional land-use schemes in the Jacksonville, Florida, metropolitan area.

OUTLINE OF METHODOLOGY

In detailed evaluation, a transit system is specified and ridership estimates are determined from sophisticated travel simulation models. The resulting patronage permits the calculation of revenue and the computation of both system operating and capital costs to satisfy the forecast demand. In parametric analysis, various levels of modal split are assumed for alternative test systems.

The resulting revenue and cost for each hypothetical estimate of patronage can be calculated, and an order-of-magnitude assessment can be made of the feasibility of long-range transit plans.

The methodology used in parametric analysis generally conforms to the transportation planning process used throughout the nation. Because of the complex array of variables that influence travel and the extensive data required to describe an urban area, the process relies substantially on the program battery of the Urban Mass Transportation Administration. In essence, land-use and socioeconomic data are converted to total person travel desires by using trip generation and distribution models. As noted previously, modal split is determined by assuming several capture rates that are also applied to the results of the transit network assignment. Plan evaluation for sketch-planning purposes is performed by assessing system results in terms of patronage, revenue, and costs. Unlike the conventional detailed testing conducted at the zonal level the sketch planning was performed at a larger areal scale—the census tract. The portion of the sketch-planning process that interfaces with traditional planning steps and is unique to parametric analysis consists of the following three steps:

1. Network development—Network development involves two sequential tasks. The first is the delineation of the guideway alignment and station locations. The parametric analysis is partially network dependent in that routes and stations for the guideway system must be specified. The system of surface (local and feeder) bus routes is not identified by alignment. Instead this "background" transit component is described by levels of service necessary to support the exclusive transit facilities at various capture rates. The second task is to define the range of transit technologies to be considered in the analysis.
2. Identification of parameters—The second step in the analysis is to specify the several factors or parameters that influence transit performance. These parameters include both supply and demand characteristics of the guideway system. Demand parameters would include hourly distribution of riders and capture rates. Supply parameters would describe operating speeds, seating capacity, and dwell time as well as operating and capital unit costs.
3. Network evaluation—The final step in the parametric analysis is to determine the patronage, revenue, and cost associated with each test condition. In this way, the supply characteristics of each test situation and their accompanying costs can be contrasted with patronage and revenue results to assess their financial workability. Alternatives that require subsidy beyond anticipated funding levels can be eliminated from further detailed testing.

To facilitate the parametric analysis, a computer program called sketch planning of rapid transit (SPORT) was used. SPORT performs the calculations necessary for sketch-planning testing. The data input includes the information from the traditional planning process (e.g., ULOAD line volumes) and the parameters specified for each test condition. The output of the program is various operating statistics, such as miles of service and vehicle requirements, as well as the financial results of the analysis—revenue, cost, and margin.

NETWORK DEVELOPMENT

To provide the proper framework for conducting the analysis, two steps were undertaken: (a) specification of test systems including route alignments and station locations and (b) identification of alternative vehicle technologies. The first step in network development was a review of population, employment, and travel forecasts for the horizon year 2000. These data provided information on the location and intensity of activity in the urban area that was used to specify major travel corridors to be served by the guideway system. Two test systems were developed for testing purposes. One concept consisted of 63 km (39 miles) of line and 38 stations; a more ambitious scheme called for 93.5 km (58 miles) of line and 50 stations. For purposes of simplification, only the results for the smaller system are reported in this paper. In addition, each of the transit test systems was analyzed for four different technologies: high-capacity rapid transit (HCRT), intermediate-capacity rapid transit (ICRT), low-capacity rapid transit (LCRT), and busway. These four generic systems were selected because they have inherently different operating parameters that can be used in a comparative analysis for sketch-planning purposes.

IDENTIFICATION OF PARAMETERS

The next step in the analysis was to specify the several factors or parameters that influence transit performance. Only a single set of parameters was identified for each guideway mode, but it should be recognized that each parameter could be varied to test the sensitivity and consequences of different values. Since the intent of the sketch-planning analysis is to screen alternatives for subsequent detailed testing, only a single set of parameter values was used. The key parameters and values used in the analysis are given in Tables 1 and 2. Other parameters include capture rate, hourly distribution of riders, policy headways, load factor, economic life, interest rate, and surface bus parameters.

NETWORK EVALUATION

Since the principal purpose of this analysis was to assess the feasibility of instituting an exclusive-guideway system in Jacksonville by the year 2000, the evaluation considered three fundamental measures: patronage, revenue, and cost. The value of each of these performance indicators was deemed sufficient to provide the information necessary to determine the feasibility of such a system for metropolitan Jacksonville.

The parametric analysis was performed for three land-use concepts, two transit plans, and four transit technologies. This resulted in 24 test situations. Since each test situation was performed at 11 capture rates, the results of 264 alternatives were tested. For simplicity, the detailed results of the parametric analysis are presented here for only a single land-use plan and transit alternative. All revenues and costs have been projected in 1976 dollars under the assumption of economic equilibrium (i.e., any escalation attributed to inflation would affect revenues and costs to the same extent). For this reason, the analysis does not accurately reflect program cash flows, but it is adequate to render a preliminary decision on the financial feasibility and potential patronage of fixed-guideway mass transit in the study area.

Patronage

Under parametric analysis, estimates of ridership were developed through the application of various capture rates to the total trip market. Since nearly 2.7 million daily person trips are expected to make up the total travel market in 2000, transit patronage may range

Table 1. Input values to parametric analysis: capital cost and service life of guideway system.

Technology	Unit Cost ($000s)			Life (years)		
	Guideway[a]	Station	Vehicle	Guideway	Station	Vehicle
HCRT	13 440	4000	650	40	40	20
ICRT	7 769	3000	500	40	40	20
LCRT	4 475	2000	100	40	40	20
Busway	6 774	1500	70	40	40	12

Note: 1 km = 0.62 mile.
[a]Cost per kilometer.

Table 2. Input values to parametric analysis: guideway operating characteristics.

Characteristic	HCRT	ICRT	LCRT	Busway
Speed (km/h)	97	80	40	72
Acceleration (m/s^2)	0.45	0.45	0.45	0.45
Deceleration (m/s^2)	0.45	0.45	0.45	0.45
Dwell time (s)	25	20	15	30
Seating capacity	80	40	15	45
Train consist (cars)	8	4	2	
Minimum headway (s)	90	45	15	25
Layover	6 min/ round trip	4 min/ round trip	2 min/ round trip	10 percent of running time
Cost per kilometer ($)	1.03	0.44	0.22	0.72

Note: 1 km = 0.62 mile; 1 m/s^2 = 3.28 ft/s^2.

quite significantly from 26 900 daily trips under an assumed capture rate of 1 percent to 2 690 000 daily journeys under an assumed capture rate of 100 percent. Nonetheless, experience in other communities with comparable exclusive-guideway-bus systems suggests that capture rates may reasonably be expected to vary from about 5 to 25 percent.

Although aggregate transit demand is a useful guideline, of equal importance is the assignment of patronage to the test network to determine ridership on each of the constituent route segments. These more detailed estimates of patronage (maximum load volumes) function as inputs to the computations of the headways and vehicle requirements necessary to satisfy demand. In addition, the transit assignment indicates the number of trips that are not conveniently served by the guideway system and would rely on local bus service. Only about a third of the 269 200 daily trips assigned to the transit network would use the exclusive transit facility system at an assumed 10 percent capture rate.

Revenue

Since revenue is a function of ridership, revenue forecasts were developed by considering both modal-split percentages and rate of fare. Revenue projections for the parametric analysis were prepared for 11 capture rates at an average fare of 30 cents. Annual revenue in 2000 would range from $2.34 million under an assumed capture rate of 1 percent to $234.05 million if all trips in the region employed either test system. More likely, however, annual revenue would probably vary from $11.70 million to $58.51 million, which is representative of current experience and corresponds to modal-split percentages of 5 and 25 percent, respectively.

Costs

To provide an accurate assessment of total system costs, it is necessary to describe the operating and capital expenditures associated with the guideway transit concept and for each of the four technology options under consideration.

Capital Expenditures

Capital expenditures represent the essential long-term assets of the system, including the acquisition of vehicles and the construction of guideway and stations. As Table 3 indicates, the cost of constructing the transit concept would be substantial regardless of the generic transit mode selected for implementation. Institution of the small-vehicle system (LCRT) would require the least capital outlay. At the other end of the spectrum, inauguration of an HCRT system would require the greatest capital expenditure and would be about three times as costly as the small-vehicle option. Both ICRT and busway occupy intermediate cost positions, but the bus system is the less expensive to construct.

In addition to expenditures for guideway and stations, fleet size and costs must be determined for the assumed complementary bus system as well as for the exclusive transit facility plan. Peak vehicle needs are related to several factors, including maximum load values, vehicle capacity, headway policies, operating speed, and recovery time. The interrelationship among all of these factors accounts for the significant disparity in peak vehicle requirements (see Table 4). At all capture rates, the HCRT system would require the fewest vehicles principally because of its superior operating speed and higher seating capacities (Table 4). In contrast, the LCRT system, which has the lowest seating capacity and operating speed of the four modes, would require by far the largest number of peak vehicles. At lower capture rates, the number of vehicles required does not change because headway rather than demand governs the frequency of service.

Interestingly, the number of buses allocated to surface transit functions, particularly local services, would decline at increasing capture rates. This phenomenon is a result of two related assumptions: (a) The effectiveness of local service, or the number of passengers carried per vehicle kilometer operated, is directly proportional to the capture rate and (b) as the relative number of mass transit users increases, the accentuation in demand, or peaking, diminishes. Thus, as more riders are transported at higher levels of effectiveness, the number of buses required for peak service is presumed to decrease.

Because the busway alternative offers the lowest cost per seat ($1555) of the four technologies, it would necessitate the least initial capital expenditure for vehicles. The ICRT system, which exhibits the most expensive capital cost per seat ($12 500), would result in the highest overall vehicle cost at all capture rates under both network alternatives.

The relative differences in total vehicle cost among modes are somewhat mitigated when vehicle expenditures

Table 3. Construction costs for guideway system.

	Cost ($000 000s)					
	Unit		Construction			
Technology	Guideway*	Stations	Guideway	Stations	Total	Amortized
HCRT	13.40	4.00	844.67	152.00	996.67	83.58
ICRT	7.75	3.00	488.25	114.00	602.25	50.50
LCRT	4.46	2.00	281.23	76.00	357.23	29.95
Busway	6.76	1.50	425.75	57.00	482.75	40.48

Note: 1 km = 0.62 mile.
*Cost per kilometer.

Table 4. Peak vehicle requirements for bus and guideway systems.

	Surface Bus			Guideway			
Capture Rate (%)	Local	Feeder	Total	HCRT	ICRT	LCRT	Busway
1	103	6	109	45	50	63	53
3	256	14	270	45	50	126	53
5	362	20	382	45	64	205	60
10	513	27	540	57	120	407	113
15	581	32	613	82	178	609	165
20	609	45	654	107	235	811	219
25	618	56	674	132	293	1015	273
30	615	67	682	157	353	1216	329
50	564	103	667	260	584	2027	544
75	489	133	622	390	876	3039	816
100	427	155	582	520	1168	4052	1087

are amortized and translated into annual costs:

	Annual Vehicle Cost ($000 000s)				
		Guideway			
Capture Rate (%)	Surface Bus	HCRT	ICRT	LCRT	Busway
1	1.01	2.74	2.55	0.64	0.49
3	2.51	2.74	2.55	1.28	0.49
5	3.55	2.74	3.26	2.09	0.56
10	5.02	3.47	6.11	4.15	1.05
15	5.69	4.99	9.06	6.20	1.53
20	6.07	6.52	11.97	8.26	2.03
25	6.26	8.04	14.92	10.34	2.54
30	6.33	9.56	17.98	12.39	3.06
50	6.20	15.83	29.74	20.65	5.05
75	5.78	23.75	44.61	30.95	7.58
100	5.41	31.66	59.48	41.27	10.10

For example, at the 10 percent capture rate, ICRT vehicle costs (the most expensive) are about seven to eight times greater than the corresponding busway vehicle costs (the least expensive). However, on an annual basis, ICRT is only about five times as costly as the busway option because of the different economic life assumed for each technology option. Similarly, at the 10 percent capture rate, the total vehicle costs of LCRT are roughly 20 percent higher than those of HCRT. On an annual basis, the relative difference between rapid transit and the small-vehicle system is reduced even further and the absolute monetary difference is less pronounced.

As given in the table below, summation of all capital costs on an amortized basis reveals that HCRT would be the most expensive alternative at all modal splits although its relative disadvantage diminishes at increasing capture rates. On the other hand, LCRT would be least costly at capture rates of approximately 30 percent or less whereas at higher capture rates the busway system would consume the lowest level of capital resources:

	Annual Guideway System Cost ($000 000s)			
Capture Rate (%)	HCRT	ICRT	LCRT	Busway
1	87.33	54.06	31.61	41.99
3	88.82	55.56	33.75	43.48
5	89.87	57.31	35.59	44.59
10	92.07	61.63	39.12	46.55
15	94.24	65.26	41.85	47.71
20	96.17	68.55	44.29	48.59
25	97.88	71.69	46.56	49.28
30	99.48	74.82	46.68	49.87
50	105.61	86.44	56.80	51.73
75	113.11	100.89	66.69	53.84
100	120.65	115.39	76.63	55.99

Operating Expenditures

Operating expenditures include costs for items such as wages and salaries, maintenance of equipment and ways, and energy consumption. As indicated in the table below, more capital-intensive HCRT and ICRT systems would generally be less costly to operate than the LCRT and busway alternatives at capture rates of 15 percent or more:

	Annual Operating Cost ($000 000s)				
		Guideway			
Capture Rate (%)	Surface Bus	HCRT	ICRT	LCRT	Busway
1	3.82	7.64	3.24	1.62	5.37
3	9.83	7.64	3.24	2.49	5.37
5	14.35	7.64	3.67	3.95	5.70
10	21.91	8.65	6.01	7.81	8.91
15	26.61	11.25	8.86	11.67	13.10
20	30.29	14.18	11.76	15.57	17.34
25	33.18	17.52	14.64	19.44	21.56
30	35.55	20.89	17.55	23.32	25.88
50	42.47	34.52	29.18	38.85	42.97
75	48.68	51.60	43.74	58.27	64.44
100	53.89	68.79	58.30	77.68	85.85

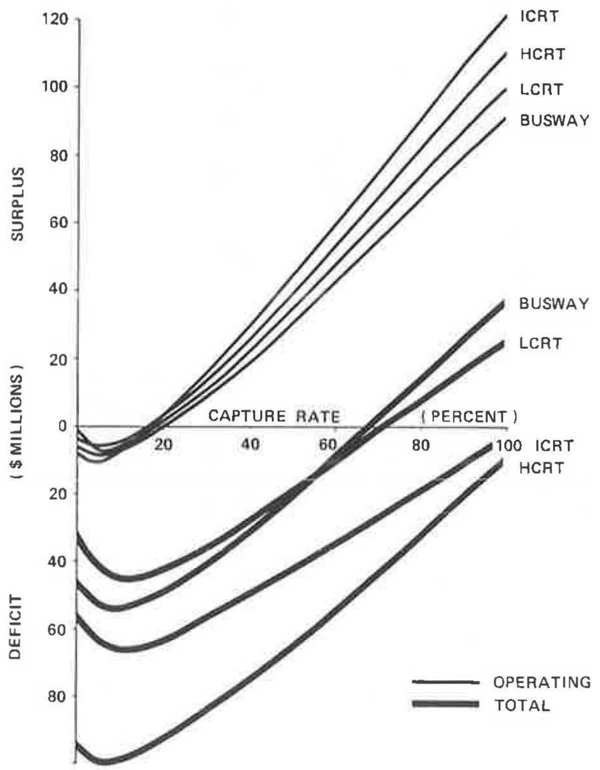
At lower modal-split values, the performance of HCRT and ICRT is detrimentally affected by the requirement to provide schedules that would be governed by policy rather than demand. For this reason, the LCRT and busway options would provide some cost saving at the more realistic capture rates—less than 15 percent.

A compilation of both annual operating and capital cost indicates that LCRT attains the lowest overall cost of the four options under consideration for capture rates of 30 percent or less:

	Total Annual Cost ($000 000s)			
Capture Rate (%)	HCRT	ICRT	LCRT	Busway
1	98.79	61.12	37.05	51.18
3	106.30	68.63	46.07	58.69
5	111.86	75.33	53.90	64.64
10	122.62	89.55	68.83	77.37
15	132.13	100.74	80.14	87.42
20	140.64	110.60	90.15	96.23
25	148.57	119.51	99.18	104.02
30	155.92	127.92	107.55	111.30
50	182.60	158.09	138.12	137.17
75	213.38	193.31	173.63	166.96
100	243.33	227.59	208.20	195.73

When the modal-split ratio surpasses 30 percent, the busway alternative would appear to be most satisfactory. Nevertheless, the relative disadvantage of the more capital-intensive systems (HCRT and ICRT) diminishes at increasing market shares.

Figure 1. Operating and total annual cost margin for four transit technologies.



Evaluation of Costs and Revenues

Comparison of system revenues and costs demonstrates that all four transit modes would require considerable subsidy at most capture rates. If only operating costs are considered, ICRT would appear to be the most acceptable mode since it would provide "break-even" operation at about the 15 percent capture rate (see Figure 1). Even under a more realistic modal-split ratio of 10 percent, the operating deficit associated with the ICRT option is estimated to be a comparatively low $4.52 million.

When total costs are taken into account, however, the less capital-intensive LCRT system would require the lowest level of public assistance for capture rates up to 30 percent whereas the busway option would result in the lowest deficit for modal-split ratios greater than 30 percent.

RESULTS

The results of the parametric analysis would suggest that a guideway system for the Jacksonville urban area is financially feasible at reasonable capture rates. This is especially true since the plan would be eligible for 80 percent capital assistance and as much as 50 percent of the operating deficit. More detailed testing of a guideway system would thus appear to be warranted. The results also suggest that a technology that includes the elements of ICRT and LCRT is the preferred mode. Had the financial results of the sketch-planning analysis demonstrated that the cost of exclusive transit facilities was prohibitive at reasonable market shares, then capital-intensive options would be eliminated from costly detailed testing.

CONCLUSIONS

Although the analysis performed in Jacksonville represents only a single case, certain conclusions can be drawn about parametric analysis:

1. In view of the increasing concern for testing a broad range of land-use and transit options, there is a need for sketch-planning tools to supplement the accepted testing procedure.
2. Parametric analysis represents a simple and inexpensive technique for assessing the feasibility of exclusive transit facilities and candidate modal technologies in a metropolitan area.
3. An initial screening of transit alternatives can save the expense of a more detailed examination of a transit system or land use that will ultimately prove infeasible. Furthermore, alternatives that successfully emerge from the parametric analysis can be subjected to more rigorous scrutiny than if only detailed testing procedures were utilized.
4. Because parametric analysis does not rely on a modal-split model but assumes various capture rates, it permits alternative evaluation to proceed concurrently with model calibration.
5. Although only a single set of values for each mode was defined for each parameter, the values could be varied to permit sensitivity analysis as well as assess the consequences of different values.
6. The fact that parametric analysis is readily adaptable to computer processing means that many alternatives and parametric values could be tested quickly and inexpensively.

Preliminary Screening of Transit Corridor Alternatives

Ronald W. Eash and Arnold H. Rosenbluh, Chicago Area Transportation Study

Part of a major analysis of transit corridor alternatives done by the Chicago Area Transportation Study is presented. A method was developed to screen out, for further study, a limited number of proposed transit improvements from a large number of suggested alternatives for a corridor. The principles of this screening are (a) that some alternatives are not consistent with patronage in the corridor and (b) that some alternatives are dominated by others. The screening methodology is discussed, and the use of corridor supply and demand functions for evaluation and the estimation of these functions are presented. Demand and supply estimates prepared for several light-

rail alternatives for Chicago's Southwest Corridor are then subjected to preliminary screening.

It is now federal policy that any proposed major capital investment in an urban travel corridor that is funded by the Urban Mass Transportation Administration (UMTA) must be subject to an alternatives analysis (1, 2). That study must evaluate different line-haul alignments and modes for use in the corridor and also investigate whether low-cost improvements of the transportation system management (TSM) type can be substituted for a capital-intensive alternative. The policy specifies a number of items to be included in the evaluation, including operating and capital costs, projected patronage, environmental impacts, and energy consumption.

These alternatives analyses have generally combined the methodologies of urban transportation planning and engineering location studies. The studies feature a scaled-down application of the sequential travel demand models developed over the past two decades to project travel demand. Supply characteristics of the alternatives are estimated in a separate engineering feasibility study.

There are at least two major problems, however, in using these conventional methods:

1. Although a large number of alternatives can be proposed for review and consideration, only a handful of corridor alternatives can be tested. A variety of corridor transit alternatives can be generated by considering different modes and major alignment variations within the corridor. One can even propose combinations of modes (feeder bus combined with rail transit service) or alternative types of operation within a single mode (various combinations of express and local corridor service).
2. The travel demand models require a fairly detailed representation of the transit alternative under study but offer the analyst little prior guidance in the design of the supply attributes of an alternative. To estimate patronage, the models require that transit lines and service frequencies be specified. But, since these supply characteristics depend on patronage, there must be some iteration between the specification of supply characteristics and the application of the demand models. In practice, this relation is suppressed to the point where separate agencies are often assigned the responsibility for estimating supply characteristics and attracted patronage for an alternative.

This paper discusses part of a study of alternatives for a travel corridor completed by the Chicago Area Transportation Study. A preliminary evaluation of a large number of corridor line-haul and alignment alternatives led to the selection of a manageable number of proposed corridor line-haul investments for more detailed study. Objectives for this preliminary screening were to identify (a) line-haul alternatives that are not technologically consistent with the demand attributes of the corridor and (b) alternatives that are clearly dominated by another alternative.

PRELIMINARY SCREENING METHODOLOGY

Figure 1 summarizes the methodology used for the preliminary screening of mode and alignment alternatives for a corridor. The first steps at the top of this figure are designed to create a set of corridor demand functions for transit service. These demand functions are general relations between patronage on the corridor line-haul facility and the frequency of service and line-haul travel time. Thus, the demand functions are not dependent on mode; they are, however, created by using conventional sequential models of travel demand.

An initial estimate of the patronage on an alternative is completed by entering these demand functions at the appropriate frequency of service and line-haul travel time. Different alignments and station spacings are taken into account by adjusting line-haul travel times to compensate for changes in access times. A new service frequency is then computed based on the capacity required to accommodate estimated patronage. This latest frequency is then compared with the earlier value of frequency used in estimating patronage. If there is a large discrepancy between the two frequencies, patronage must be recomputed and the procedure iterated until estimated patronage and service frequency agree.

At this point, it may be possible to eliminate some alternatives because the line-haul mode characteristics are such that no equilibrium between corridor travel demand and frequency of service can be attained. Even if an alternative can be eliminated, the entire procedure is repeated until all alternatives are considered. Next, alternatives (called dominated) whose performance is clearly inferior to that of another alternative can be eliminated. The remaining alternatives continue to the more detailed stage of the analysis.

EQUILIBRIUM IN TRANSIT SUPPLY AND DEMAND

The two objectives of preliminary screening rely heavily on an understanding of the supply and demand characteristics that exist in a major travel demand corridor. Some general functions that establish the framework for the preliminary evaluation are shown in Figure 2. The maximum-load-point volume (V) that occurs in the corridor is plotted on the horizontal axis. In a typical radial corridor, this point is located adjacent to the central business district (CBD). The vertical axis shows the frequency of service (F) that is provided by the basic unit of capacity for a particular mode, the individual vehicle, or a group of vehicles combined in a train.

The supply function shown in this figure relates the frequency of service offered by the line-haul facility in the corridor to the maximum-load-point volume. This function implies that, provided there is service in the corridor, some minimum level of service is offered. It also implies that additional service is offered as V increases, depending on the capacity of the vehicle or train of vehicles. Since capacity is added in regular increments, it seems logical that a supply function should have a roughly linear shape over the range of maximum-load-point volumes at which the function is defined.

The second curve shown in Figure 2 ties demand in the corridor, measured at the maximum load point, with the frequency of line-haul service offered in the corridor. This function must be generally convex since travel demand in a corridor is not unlimited; it must reach some maximum level and not increase regardless of the frequency of service offered.

The curves shown in Figure 2 would change depending on the specific characteristics of an alternative. The slope of the supply function would vary as the capacity of the vehicle or train used to provide service changes. The demand function varies because different alternatives feature different line-haul speeds and alignments. An alternative with a faster line-haul speed would have a greater demand than a slower alternative at the same frequency of service.

TECHNICAL FEASIBILITY

Technical feasibility means that the intersection point between the demand and supply functions for an alter-

Figure 1. Methodology for preliminary screening of alternatives.

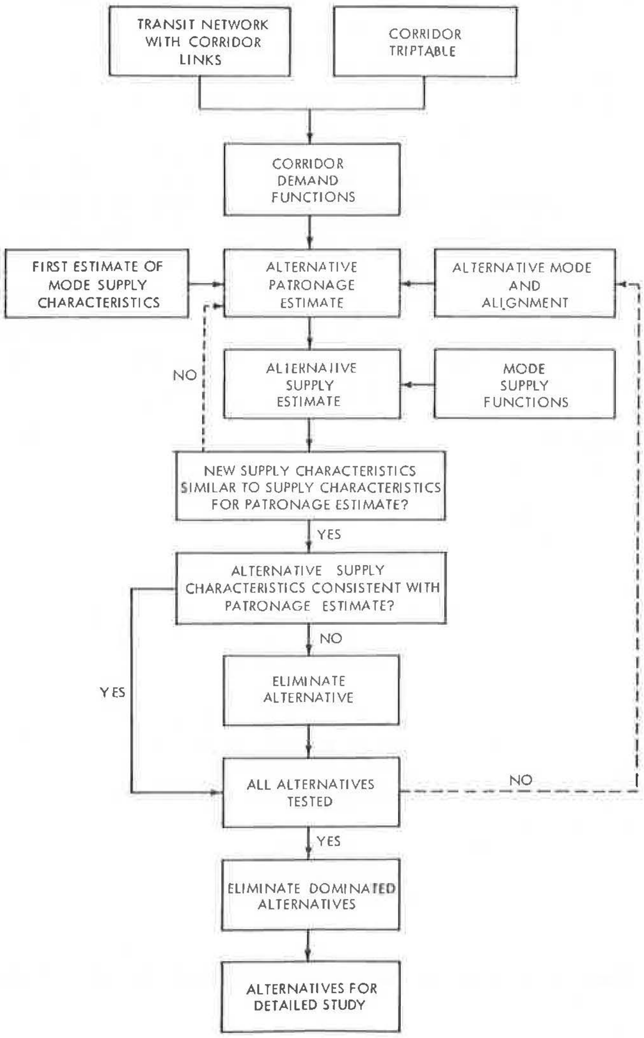
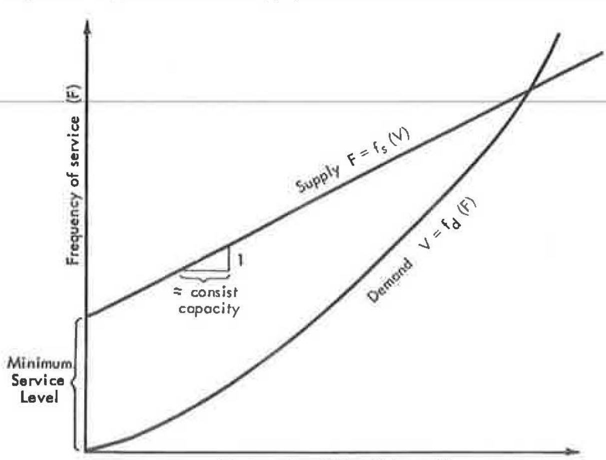


Figure 2. Typical corridor supply and demand functions for transit.



native must be at a service frequency at which the line-haul mode of the alternative can operate. The available technology for the line-haul mode of the alternative must permit a frequency of service that meets corridor demand.

This first requirement is shown in the upper part of Figure 3. The dashed line indicates the technically feasible range of service frequencies that are possible with the alternative's mode. The supply-demand intersection occurs well above a feasible service frequency. This could be remedied by changing the technology of the mode, considering a larger vehicle, or connecting a number of vehicles into a train. This would decrease the slope of the supply curve so that the intersection occurs below the feasible boundary shown in Figure 3.

A second aspect of technical feasibility is that the supply-demand intersection point must be at a satisfactory level of corridor demand. This usually implies that the equilibrium travel demand carried by the proposed line-haul facility must exceed existing line-haul patronage. This is shown in the lower portion of Figure 3, where the curves intercept to the left of the dashed line for current maximum-load-point patronage. The investment has the effect of decreasing the total amount of transit travel that takes place on the line-haul mode and forcing some of the original corridor riders to travel more circuitous routes in other competing transit corridors.

DOMINANCE OF ALTERNATIVES

In the preliminary evaluation of alternatives, the analyst must look for cases in which one alternative is dominated by another. This strategy leads to the diagram shown in Figure 4. The demand-supply relations for two alternatives are shown in this figure. The intersections of the two sets of supply-demand functions are such that equilibrium demand for the first alternative is greater than the equilibrium corridor demand for the second alternative. In addition, the frequency of service required for the second alternative is greater than the equilibrium service frequency of the first alternative.

The second alternative could be screened out if (a) the cost of a unit of capacity for the second alternative is greater than or equal to that of the first alternative and (b) other total weighted costs of the second alternative exceed those of the first alternative. One would anticipate that dominance of alternatives would most likely occur when two alignments of the same line-haul mode are compared since costs and technology would be almost directly comparable. Here, the definition of cost is a general index of the negative benefits of a project.

Note that the intersection between the supply and demand curves is not really a single point. Because of the crudeness of the estimating procedures used in determining demand and supply in this preliminary evaluation, it is more correct to speak of an envelope around this intersection. Again, the method is designed only to eliminate those alternatives that are clearly infeasible or dominated.

ESTIMATION OF CORRIDOR DEMAND AND SUPPLY FUNCTIONS

Corridor demand functions are developed by using available travel data from home interview surveys and the conventional travel models from urban transportation planning. The program steps to prepare the corridor demand functions are shown in Figure 5. Two sets of base data are required in this process—a transit network file and trip records from home interview surveys.

Figure 3. Two types of screening of alternatives.

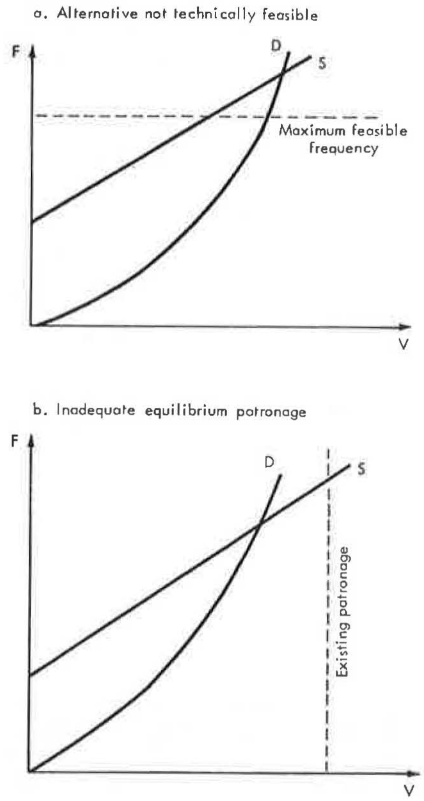
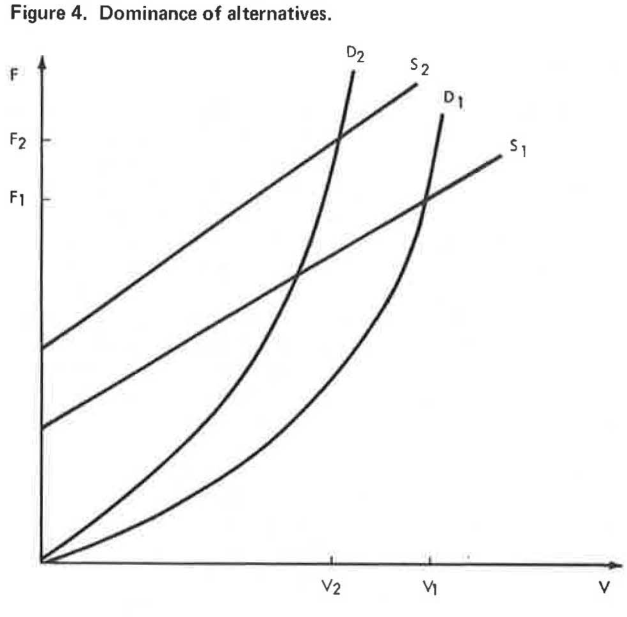


Figure 4. Dominance of alternatives.



Both data files must conform to the same system of analysis zones and be in the standard Urban Transportation Planning System (UTPS) formats (3) for processing as shown in Figure 5.

The next step in Figure 5 is to add a series of continuous links that run the length of the corridor to the original transit network file. Minimum-travel-time trees through the network are then produced by using the UTPS program UPATH, and home interview trip tables are assigned onto the network by using the ULOAD program. Both person- and transit-specific movements can be assigned to the network. Finally, the movements over the corridor links are summed by using TCORSM, a brief program written especially for the project.

Nine separate combinations of frequencies and line-haul speeds were used to estimate corridor patronage. Headways of 1, 5, and 10 min were paired with 32.2-72.5-, and 112.7-km/h (20-, 45-, and 70-mph) line-haul speeds. Patronage as a function of headway and line-haul speed was then fit to these estimates of patronage.

Supply functions for bus and rail rapid transit were developed in a study at the University of Pennsylvania (4, 5). Several regressions were fit to observations of service frequency versus maximum-load-point ridership by using data from the Chicago Transit Authority (CTA). For CTA bus operations, the peak-period supply relation from the Pennsylvania study is

$$f_B = 4.65 + 0.0136p \quad (1)$$

where f_B = buses per hour during the peak period and p = maximum-load-point ridership per hour during the peak period.

Two separate sets of supply regressions for CTA rail transit operations were prepared in the Pennsylvania study. One equation estimates the number of trains per hour, and a second estimates the number of cars in these trains. The equation for peak-period train frequency is

$$f_R^T = 9.94 + 0.000\,58\,p \quad (2)$$

where f_R^T = trains per hour during the peak period. The corresponding supply regression for cars per hour is

$$f_R^C = 10.27 + 0.011\,41p \quad (3)$$

where f_R^C = cars per hour during the peak period.

Supply function regressions for the remaining modal alternatives—new technology and commuter rail—were not developed in the Pennsylvania study. Supply functions for these modes were assumed to be based strictly on capacity. For a new technology, this assumption is probably correct. Such a mode would likely be demand responsive, and minimal service without demand would not exist (the supply function would intercept the origin). It is more difficult to estimate the supply function for commuter rail since commuter-rail operations in Chicago vary from transitlike operation to a frequency of only one or two trains per day. To develop a single supply function for this range of operation is probably impossible.

USE OF PRELIMINARY SCREENING TO EVALUATE LIGHT-RAIL ALTERNATIVES FOR SOUTHWEST CORRIDOR

Three alternative light-rail alignments were considered in the analysis of alternatives for Chicago's Southwest Corridor. These alignments and the location of the corridor are shown in the map in Figure 6. All of the alternative light-rail alignments make some use of existing railroad right-of-way in the corridor. Except for sections that are in the Chicago CBD, the alignments are to be on grade-separated right-of-way.

The major features of these light-rail alignments are as follows:

1. Alternative 1 begins on the west at Harlem Avenue, runs eastward on existing railroad right-of-way to Western Avenue, and continues north to another rail right-of-way. Finally, this alternative continues northeasterly along the existing rail line before it turns northward to a terminal that connects with the existing

Figure 5. Preparation of corridor travel demand functions.

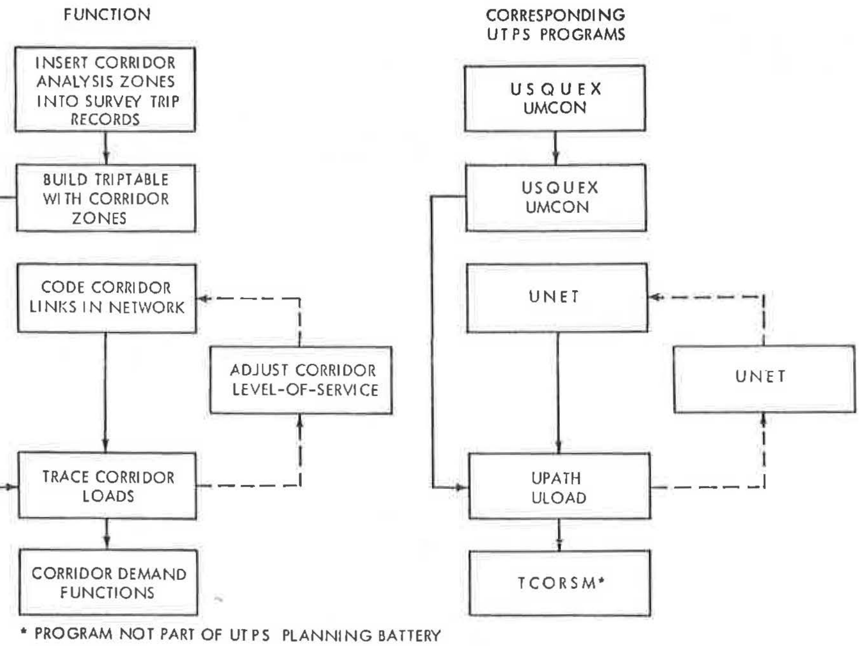
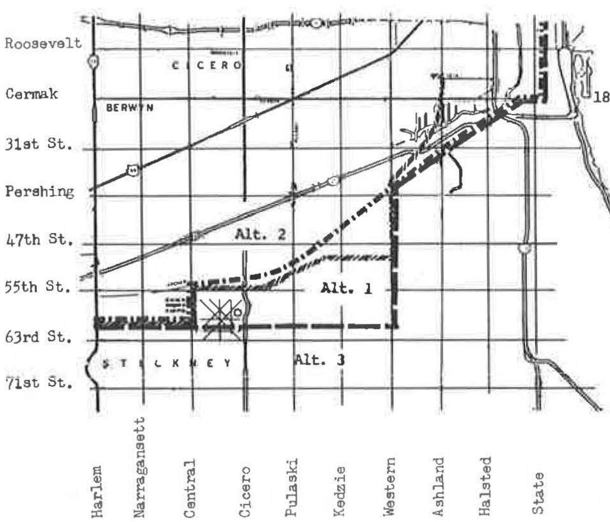


Figure 6. Light-rail alternatives for Chicago's Southwest Corridor.



Douglas Park rail transit line.

2. Alternative 2 follows the same alignment as alternative 1 until it reaches Pulaski Road, and then it continues northeasterly along Archer Avenue to Western Avenue where the alignment changes to an adjacent rail right-of-way. The alternative continues along the rail right-of-way to 18th Street, turns east to connect with State Street, then runs north along State into the downtown area.

3. Alternative 3 begins at 59th Street and Harlem Avenue, goes east on 59th under Midway Airport to Western Avenue, and turns north along Western. It then connects with the rail right-of-way adjacent to Archer Avenue at Western and continues into the downtown area on the same alignment as that used by alternative 2.

The U.S. standard light rail vehicle is the assumed vehicle for all alternatives. It seats 68 passengers and has a maximum speed of 89 km/h (55 mph). A 20-s station dwell time is assumed. If one assumes this dwell time and normal vehicle performance, an average speed of 40.8 km/h (25.2 mph) results when stations are spaced at 0.8-km (0.5-mile) intervals, and an average speed of 56 km/h (34.6 mph) is attained at station spacings of 1.6 km (1 mile) (6).

Demand Functions

A summary of data from several of the corridor demand runs is given in Table 1. The table gives the peak 2-h inbound trip interchanges between nine points in the corridor and the Chicago CBD. For the interchanges given, four different combinations of line-haul travel speeds and headways are assumed: Line-haul speeds of 32.4 km/h (20 mph) and 72.9 km/h (45 mph) are paired with 1- and 5-min headways. Interchanges given in Table 1 are only existing transit trips assigned onto the corridor links that run along Archer Avenue and do not include any divertible automobile trips. Numbers of interchanges given in the table correspond to patronage at the maximum load point just east of Halsted Street.

Direct application of these demand estimates to the alternatives is not possible since the alternatives differ in several important ways from the abstract corridor links used for the demand estimates. The values given in Table 1 must be adjusted for the different station spacings, slightly different alignments, and different line-haul speeds and headways of the alternatives. Demand estimates are based on a line-haul facility that has access at 1.6-km (1-mile) intervals and an Archer Avenue alignment; these characteristics do not agree with any of the light-rail alternatives. Headways and line-haul speeds other than those given in Table 1 must also be interpolated.

Patronage on Alternative 1

The next step (see Figure 1) is to estimate patronage at the maximum load point during the peak period. An initial headway of 1 min is assumed for the light-rail line-haul alternative. If one starts at Harlem Avenue and works toward the CBD, the first trip interchange is between Harlem Avenue and the CBD. This movement

Table 1. Demand data for the Southwest Corridor.

Speed (km/h)	Headway (min)	Number of Trip Interchanges to CBD From: Harlem	Narra-gansett	Central	Cicero	Pulaski	Kedzie	Western	Ashland	Halsted
32.4	5	674	513	576	773	1866	1112	2518	406	1654
32.4	1	674	513	576	773	2136	1112	3949	979	2895
72.9	5	674	513	576	1172	2917	3259	5234	-	5225
72.9	1	826	513	576	1172	3063	3391	5915	217	5649

Note: 1 km = 0.62 mile.

requires a trip of 17.8 km (11 miles) along alternative 1. Using an average speed of 56 km/h (34.6 mph) means that the line-haul travel time on alternative 1 is 19.1 min. It takes another 11 min to reach the CBD by using the existing Douglas Park rapid transit.

But note that the alignment of this alternative is not along Archer Avenue when it intersects Harlem Avenue; it is 0.8 km (0.5 mile) south of Archer at this point. Thus, some users will travel less distance to reach the line-haul service, and some will be forced to travel farther than the demand estimates assume. To correct for this, an estimate is made of the proportion of users whose line-haul access has been improved and those whose access has been worsened. This can be done well enough by simply reviewing data on population or dwelling units in the approximate service area of the station. Line-haul travel times for each group are then adjusted to reflect their access situation.

For the interchange from Harlem Avenue, 40 percent of the patrons are estimated to benefit from the alignment being 0.8 km (0.5 mile) farther south and 60 percent to be farther away than if the line were on Archer Avenue. The time adjustment is computed by assuming that access to the line-haul service is by feeder bus service, which travels at 16.2 km/h (10 mph). Individuals with improved line-haul access save 3 min whereas those with worse access have 3 min added to their travel time. The line-haul speeds to be used in the demand estimates work out at 42 km/h (25.9 mph) for the group with improved access and 34.3 km/h (21.2 mph) for those with poorer access. These speeds are computed by dividing the distance along the Archer Avenue alignment used in the demand estimates by the adjusted travel times.

The demand values given in Table 1 are interpolated in the following way. First, although it is not necessary at this point because of the assumed 1-min headway, demand at headways different from those shown in the table must be estimated:

$$D_v^h = D_v^5 + (D_v^1 - D_v^5)[(5 - h)/4] \quad (4)$$

where D_v^h = peak 2-h travel demand at headway h and line-haul speed v and h = line-haul headway (min). The next interpolation is for line-haul speed:

$$D_v^h = D_{v1}^h + (D_{v2}^h - D_{v1}^h)[(v - v_1)/(v_2 - v_1)] \quad (5)$$

where v_1, v_2 = base line-haul speeds in Table 1. For the interchange from Harlem Avenue to the CBD, the demand at 42 km/h (25.9 mph) equals 710 trips. The demand at 34.3 km/h (21.2 mph) is 680 person trips.

Finally, the location correction is applied by weighting the above two demand figures according to the fraction of trips in each category:

$$D^1 = \lambda D_{42.0}^1 + (1 - \lambda)D_{34.3}^1 = 0.4(710) + 0.6(680) = 690 \quad (6)$$

where λ = the fraction of trips with improved access to the line-haul facility.

Working through all the interchanges to the CBD gives the following demand values for alternative 1:

From	Interchanges to CBD
Harlem	690
Narragansett	510
Central	580
Cicero	790
Pulaski	2 150
Kedzie	960
Western	3 800
Ashland	1 110
Maximum load point	10 590

Patronage at the maximum load point (just before alternative 1 connects with the existing Douglas Park service) is approximately 10 600 riders in the peak 2-h period.

At this point, the analysis has dealt only with light rail stations spaced at 0.8 km (0.5 mile). Yet, within alternative 1, closer station spacings may be considered and the calculations in the table above repeated. A change in station spacing can be approximated by adjusting the line-haul speeds in much the same way as a shift in alignment was approximated.

Supply Characteristics of Alternative 1

The supply function for light rail is adapted from the bus supply function. The constant term in the bus regression is assumed to hold for the light-rail alternative, but the coefficient for the independent variable, maximum-load-point patronage, is decreased because of greater vehicle capacity (90 persons/car is used as crush capacity) and the ability to couple vehicles into trains. The revised equation for the light-rail alternative is

$$f_{LR} = 4.65 + 0.0111\ (p/n) \quad (7)$$

where

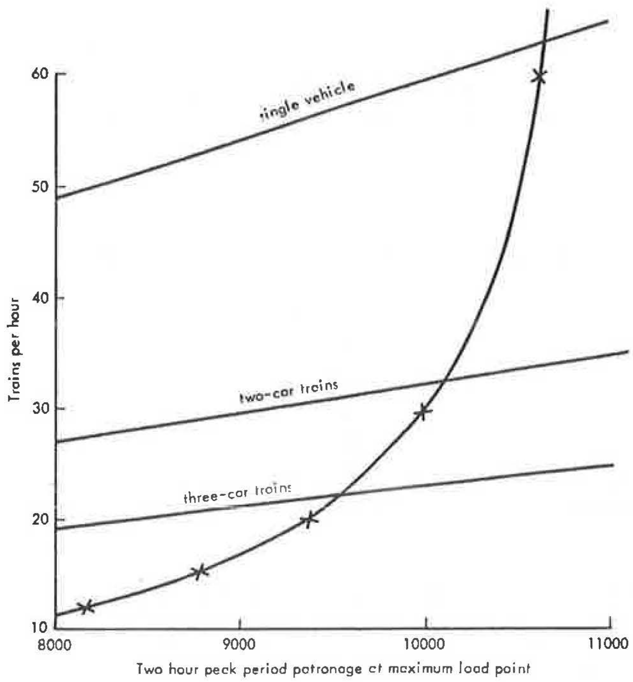
- f_{LR} = light rail trains per hour,
- n = number of vehicles in a train, and
- p = maximum-load-point ridership per hour during the peak period.

In Figure 7, the supply functions are plotted on the same graph as was the demand curve for patronage at the maximum load point. The demand curve for the first light-rail alternative is calculated by repeating the calculations given in the table above, assuming different service frequencies. The supply functions in Figure 7 are for one-, two-, and three-car trains. The three points of intersection between the demand and supply curves indicate where the amount of service offered is consistent with corridor patronage.

Evaluation

The first light-rail alternative has now passed through

Figure 7. Patronage and supply characteristics of light-rail alternative 1.



the initial level of screening. Some evaluation has also taken place. One can clearly conclude from Figure 7 that operating light rail trains with more than three cars is undesirable. The three points of intersection between supply and demand are also acceptable from both (a) the supply side, in that frequency of train operation is technically feasible, and (b) the demand side because more patrons are attracted by the service than by the existing corridor service.

To continue to evaluate the alternative, one determines whether any of the intersecting points between supply and demand is dominated by another intersecting point. But, in this example, clear dominance probably does not occur because of the trade-off between frequency of service and patronage. Operating costs are probably moving in opposition to user savings. Figure 7 does offer guidance when one is considering which alternatives should be compared with one another. For example, the modest drop in patronage caused by going from one- to two-car trains may be overwhelmingly offset by savings in operating costs. To complete the preliminary screening, the analysis of Figure 7 is directly extended to include other modal alternatives.

ACKNOWLEDGMENT

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Method for Highway Location Selection

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The professional costs associated with developing, tabulating, and evaluating alternatives in the execution of a highway location planning study have now become large enough to be considered a problem. A method is presented that minimizes the wasted efforts (and project costs) associated with testing in location planning studies and at the same time makes the study process more accurate and precise. This method of highway location selection offers the transportation planner a computer-assisted technique that can generate and then search through a large number of generated highway locations to identify optimal solutions. The traffic analysis zone is the basic element of which generated locations are composed. Zone deficiencies are determined for each zone and then used to determine zone-pair connectivities that represent the degree of importance of connecting deficient zones by a highway. A measure of effectiveness, defined as the aggregate connectivity of a location divided by its length, is used to approximate benefit/cost ratios in evaluating each generated location. The process also includes methods to account for highway-related costs (or benefits) of social, environmental, and economic impacts. This process allows an estimate of the highway benefits of a large number of location alternatives without running traffic assignments for each generated location.

The urban transportation planning (UTP) process guides the highway planner through incremental levels of detail as a project evolves. These levels begin with comprehensive urban planning and go on to sketch transportation planning, subarea transportation planning, corridor transportation planning, project location planning, and finally project design (1, 2). This paper deals with the corridor transportation planning and project location planning phases of the UTP process.

In corridor location planning, the planner must consider all reasonable solutions to an area's transportation needs. In most highway planning studies, this means the study of many potential locations and configurations for the highway system. Even after all of these preliminary alternatives have been examined, there is no certainty that the optimal (user-defined) location has been considered (the "user" referred to in this paper is the user of the method of highway location selection).

The available Federal Highway Administration (FHWA) and Urban Mass Transportation Administration (UMTA) computer packages in transportation facilitate the evaluation of preliminary location alternatives (3). However, because various state departments of transportation (and other users of computer packages) appreciate the relative ease with which network modifications and traffic assignments can now be made, extensive testing becomes the order of the day. Much of this testing could be reduced while the focus is kept on the transportation solution.

PURPOSE AND OBJECTIVE

The purpose of this paper is to present a technique that would identify highway locations that satisfy user-defined transportation objectives in areas such as congestion, energy consumption, and air and noise pollution. It is not anticipated that all possible objectives could be addressed, but at least those that are usually associated with transportation problem solving in location planning could be. The technique is designed to use the variables available in preassignment or postassignment from the FHWA and UMTA program batteries. Users familiar with these batteries will have all necessary input data.

The objective of the study is to minimize the efforts (and project costs) associated with location planning studies while at the same time making the study process more accurate and precise.

METHODOLOGY

The methodology consists of four sequentially integrated phases: (a) zone deficiency, (b) zone-pair connectivity, (c) location generation, and (d) location evaluation. These steps are shown in flowchart form in Figure 1. Computer programs were developed for each phase and then synthesized into a complete package—the highway location selection model (HLSM)—that features simple data preparation and flexible parameters.

Zone Deficiency

A project area is defined by its traffic analysis zones. The traditional approach to determining traffic deficiencies in a system is to assign a design-year trip table on a maintenance-null (do-nothing) network and then determine the levels of service on the network links.

Highway location planning determines general locations rather than exact alignments of each alternative. Therefore, it is more appropriate at this level of planning to analyze zones rather than individual links provided the zone structure is not too gross. A zone deficiency may be defined in terms of

1. Kilometers of arterial system over capacity,
2. Through vehicle kilometers of travel on the arterial system (or local system),
3. Zonal accessibility from regional markets,
4. Accidents on the street system,
5. Air pollution emissions on the street system,
6. Total energy consumption,
7. Number of trucks on the local system, and
8. Other factors.

Connectivity of Zone Pairs

Zone deficiencies identify which zones have transportation problems and are potential areas for traffic improvements. The determination as to whether these problems are isolated and thus require local improvements or are contiguous and thus require major improvements is addressed by zone-pair connectivity.

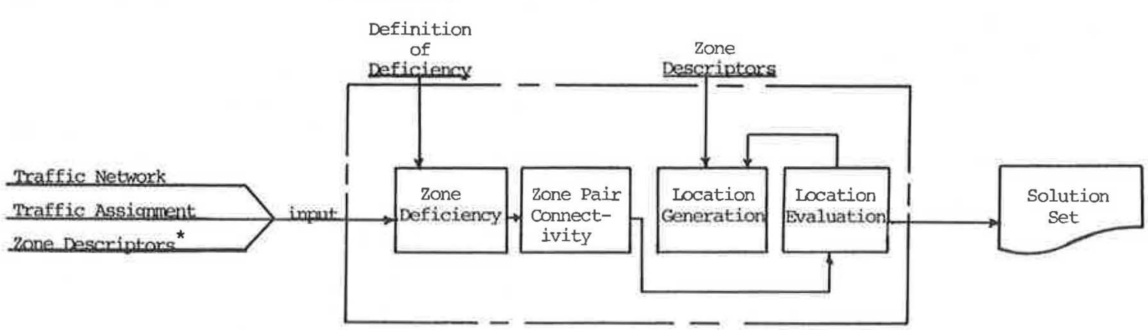
The index of zone-pair connectivity is a measure that represents the degree of importance of connecting a pair of zones by a highway. This measure uses a deficiency index in constructing a measure that rates the relative attractiveness of linking a zone pair. Connectivity is also a function of trip interchange. If a pair of highly deficient zones are adjacent to each other but have little trip interchange, then the method will give low priority to connecting them.

The analytic definition of zone-pair connectivity is

$$C_{ij} = \overline{T}_{ij} \times D_i D_j \qquad (1)$$

where

Figure 1. Highway location selection methodology.



Note: Coding of zone descriptors include specifying border zones and x-y coordinates of each zone centroid.

C_{ij} = index connectivity between zones i and j,
T_{ij} = two-way design-year daily trip interchange between zones i and j, and
D_i and D_j = deficiencies of zones i and j.

A connectivity table (or matrix) that includes all zone-pair connectivities is developed and used to evaluate alternative highway locations. Several connectivity tables can be constructed and used to evaluate alternatives from various perspectives of transportation-related deficiency, such as congestion, accessibility, safety, air pollution emissions, and energy consumption.

Whereas zone deficiency identifies which zones have user-defined transportation problems (primarily traffic congestion), zone-pair connectivity determines which zones should be linked together. Location evaluation shows how these connectivities can be aggregated to form an index that represents the total connectivity of a highway location.

Location Generation

The objective of location generation is to automatically generate all reasonable locations by connecting zones in the project area together. Because of the large number of combinations, this is done by use of a computer algorithm. Searching for the combination of contiguous zones that maximizes aggregate connectivities requires a many-to-many zone search. But, because an exhaustive search of all zone combinations on a moderately sized network (100 zones) requires more storage allocation than most computers provide and is too expensive to run even if the storage is available, alternatives to an exhaustive search had to be developed.

Methods to reduce the number of generated highway locations include restricting the number of zones to be included in a location, eliminating locations that are not geometrically feasible, and deleting inefficient locations from consideration.

The algorithm generates all two-zone combinations of border zones, evaluates these locations, and yields a best set to be generated into three-zone locations. The best locations that are three zones and longer and that satisfy geometric constraints are generated in a similar way until an upper limit of n zones is reached. The most efficient locations should total a manageable number (e.g., fewer than six) so that they can be assessed in more detail in the project design phase.

Location Evaluation

The efficiency of alternative locations is determined in the location evaluation phase. The efficiency of highway projects is typically measured by traditional benefit/cost methods. In most cases, a location incrementally accrues system road-user benefits as its length is increased. But highway costs also rise with increased length. Benefit/cost ratios indicate which locations are most economically desirable. The proposed method does not include techniques to evaluate system road-user benefits and highway costs. It does, however, offer a measure of zone-pair connectivity that represents the degree of importance of connecting a pair of zones by a highway. An aggregate connectivity index can be constructed by adding all zone-pair connectivities within the location. An analysis was performed to determine whether or not the aggregate connectivity index is correlated with road-user benefits. A correlation coefficient (r^2) of 0.47 resulted for a congestion measure of deficiency on a test project area. A highway location affects not only the problems of the zone through which the highway passes but also those of its border zones.

Connectivity of border zones is defined as the additional index of connectivity between zones within a location and zones in the location's area of influence. The inclusion of border zones in the aggregate index broadens the analysis from a location to a subsystem perspective. The combination of location-zone and border-zone connectivities is referred to here as total highway connectivity (THC) (see Figure 2). As Figure 3 shows, the correlation coefficient of total highway connectivity (based on a congestion measure of deficiency) and system road-user benefits peaks at an influence-area bandwidth 4.8 km (3 miles) distant from location-zone centroids ($r^2 = 0.87$):

$$THC(k) = \sum_{\substack{\text{all zones } i \\ \text{of location } k}} \; \sum_{\substack{\text{all zones } n \\ \text{of location } k \\ \text{where } n > i}} C_{in} + \sum_{\substack{\text{all zones } i \\ \text{of location } k}} \; \sum_{\substack{\text{all zones } b \\ \text{within} \\ \text{influence area}}} C_{ib} \qquad (2)$$

where

THC(k) = total highway connectivity index of location k,
C_{in} = zone-pair connectivity of each zone i and zone n within location k where n > i, and
C_{ib} = zone-pair connectivity of each zone i with zone b within influence area of location k.

Double counting of zone-pair connectivities is avoided by specifying n > i.

THC for each generated highway location is computed and compared with the highway's length. The ratio of THC to length serves as a measure of the efficiency of an alternative. Location length is the sum of the air-line distances between the centroids of the sequential zones of a highway alternative.

The efficiency measure replaces the benefit/cost ratio with the THC/length ratio. Whereas benefit/cost ratios determine the economic feasibility of highway alternatives, THC/length ratios determine the "degree of importance" of constructing a highway facility within a location of connected zones.

The use of THC allows the highway planner to estimate the traditional highway benefits of a location without ever running a traffic assignment for that location. Actually, this process allows an estimate of the highway benefits of an extremely large number of location alternatives.

ZONE DISINCENTIVE MULTIPLIERS

Highway planning is a complex process composed of interrelated assessments of all highway-related impacts (transportation, environmental, social, and economic). Highways have a far-reaching effect on regions and their residents. Evaluation of alternatives conducted at the location planning stage includes the following considerations (4): (a) efficiency of alternative, (b) environmental practicality, (c) consistency with local goals and objectives.

Whereas transportation efficiency is treated directly by THC per unit of location length, environmental practicality and consistency with local goals and objectives can be approached less directly by means of disincentive multipliers. Disincentive multipliers

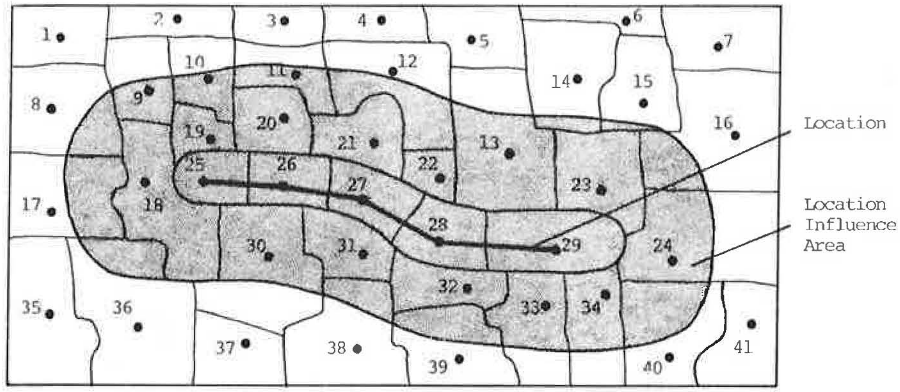


Figure 2. Total highway connectivity.

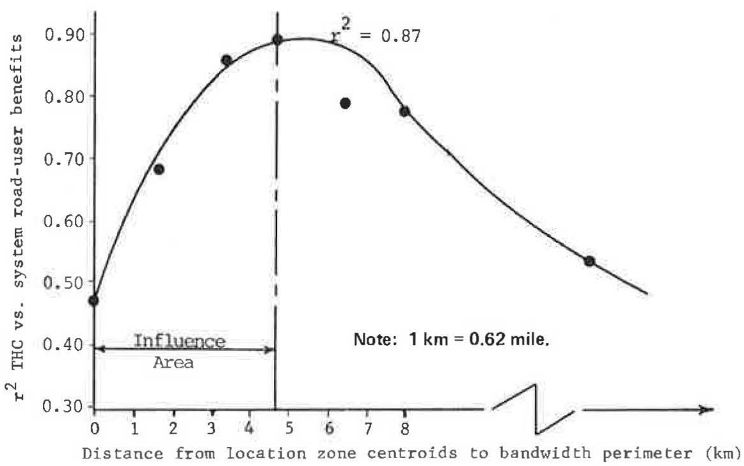


Figure 3. Influence area.

are adjustment factors of location length to represent the difficulty or undesirability of locating a highway through a particular zone. Each zone is assigned a multiplier with respect to a relative datum of unity. Zones in which highway development would be costly or difficult (e.g., high-density residential areas, commercial areas, or environmentally sensitive areas) are assigned high multipliers (e.g., 3, 4, 5), whereas zones in which no unusual disturbance is anticipated are assigned multipliers equal to one. The user has the option to preclude a particular zone from location generation. The zone would still be used to compute border-zone connectivity of generated locations nearby (within the area of influence).

TESTING

In Figure 4, the optimal location selected for a test project area without the assigned multipliers (a) is compared with the optimal location selected with the assigned multipliers (b). The location without disincentive multipliers is a half loop on the west side of the CBD of a test network in Rochester, New York; all zones are located in the urban sector of the project area. The location that results from the use of disincentive multipliers spans the project area in the east-west direction, and less than half of its zones are located in urban areas. This location is similar to an optimal location independently developed in an actual transportation study for the area (5).

The use of zone disincentive multipliers is critical to the accuracy of the methodology. The highway location selected without using multipliers (Figure 4a) is inaccurate in that its efficiency (THC/length or benefit/cost ratio)is overestimated. The multipliers assigned to urban areas of the project area guided the methodology to search for a more efficient alternative in terms of implementation costs (Figure 4b).

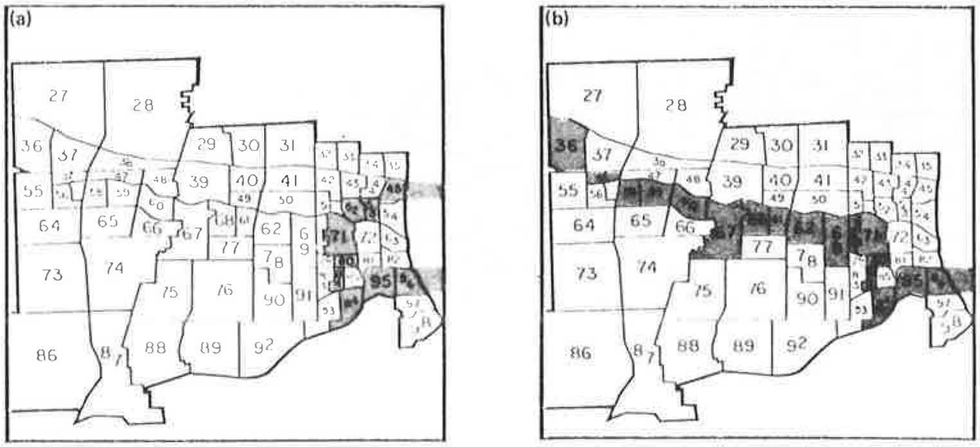
SUMMARY

The purpose of this paper is to present a technique that identifies highway locations that satisfy user-defined transportation objectives. The HLSM can identify those locations in a study area that are most deficient based on a definition of zone deficiency chosen by the user. The objective of the research was to minimize wasted efforts (and project costs) associated with testing in location planning studies while at the same time making the study process more accurate and precise. The HLSM allows the user to quickly evaluate a large number of generated highway locations without having to recode the traffic network and run a traffic assignment for each alternative. All input preparation and running of computer packages require no more than two person days. The testing of such a large number of alternatives—1000, 2000, 3000, or more—improves the accuracy and precision of the study process by broadening the domain of alternatives to include almost any reasonable solution.

APPLICABILITY OF RESULTS

The HLSM is available for further testing, particularly by those who currently use FHWA and UMTA transportation computer batteries. These are state departments of transportation, local metropolitan planning organizations, and planning agencies as well as private

Figure 4. Selected locations (a) without and (b) with zone disincentive multipliers.



consultants. The HLSM offers the transportation planner and engineer a working tool that assists in the highway location planning phase of the urban transportation planning process.

ACKNOWLEDGMENT

This paper is taken from a 1978 Ph.D. dissertation by R. P. Edelstein that was submitted to the faculty of the Potytechnic Institute of New York.

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Abridgment

Macroanalysis for Transit Integration

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The purpose of transit integration is to identify the transit services that best fit individual neighborhoods and the best combination of services to meet the needs of an urban area as a whole. The many service options include the following:

1. System options—considering different systems for the same or similar applications;
2. Application options—modifying service areas and system configurations;
3. Integration options—combining feeder-distributor and line-haul services in different ways and different patterns;
4. Level-of-service options—examining different levels of service for particular areas and transit applications;
5. Design options—altering performance characteristics, facility locations, and route alignments within the same general system configuration; and
6. Implementation options—time phasing the services and increments of services in different ways.

To investigate enough integration options to have some hope of finding a good solution, it is necessary to examine 20 or more alternatives. Even so modest a number of investigations is beyond reason if one is compelled to use the traditional network-based algorithms. The macroanalytic regionwide transportation (SMART) model of SYSTAN, Inc., has been specifically designed to explore large numbers of public transit alternatives. This model can provide the first coarse screen by which the number of transit options is reduced to manageable proportions. The model seeks breadth at the expense of detail. It does not take the place of more complex procedures but helps to focus the use of complex models on a small set of highly attractive alternatives.

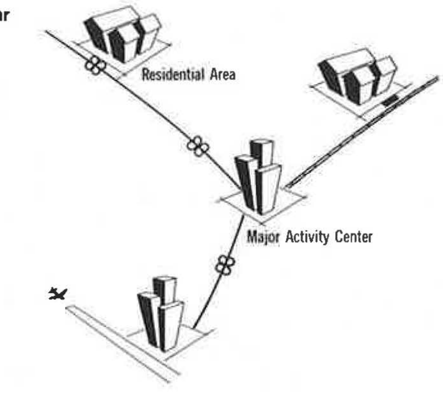


Figure 1. Modular representation.

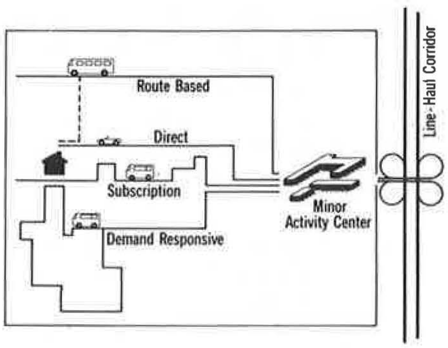


Figure 2. Residential-area service options.

DESCRIPTION OF THE MODEL

The SMART model represents urban travel at three different levels: (a) local, (b) door to door, and (c) regionwide. Local transportation is concerned with trips that take place wholly within a local module and with those portions of longer trips that occur within the local module. Local transportation is studied for two types of modules (see Figure 1): (a) residential and (b) major activity center.

Residential and major activity center modules are connected by line-haul corridors that handle all interzonal traffic within an urban region. Line-haul corridors give form to the urban structure by establishing connecting routes between the different modules. Line-haul corridors are given a circular representation: Corridors are either radial or circumferential or they emanate from the CBD. Line-haul corridors do not originate or terminate traffic; they handle traffic that originates and terminates in residential or major activity center modules.

Door-to-door trips cross module boundaries. A trip may originate in a residential module where it includes a local movement from a residential origin to an access point of a line-haul corridor. The trip continues on one or more line-haul corridors to the egress point nearest the destination. A local movement is then made from the egress point to the destination. A traveler can use a single mode between origin and destination, or modes can be changed at access or egress points of line-haul corridors or at transfer points between line-haul corridors. Door-to-door analysis takes the viewpoint of the traveler and traces the route from origin to destination, accounting for mode changes when they occur and the delays associated with them.

The SMART model accumulates regionwide data and prints regionwide summaries.

PROGRAM STRUCTURE

The SMART model calculates deterministic service and performance measures for a large number of transportation alternatives. Variance in travel time is also estimated for each of the activities that make up a trip—walk time, wait time, vehicle travel time, and transfer time.

The SMART model consists of a master computer program and nine subprograms:

1. FEEDER analyzes residential area travel;
2. LINKER analyzes line-haul-corridor travel;
3. DUMPER analyzes distribution ends of trips;
4. BCOST allocates costs between peak and off-peak hours;
5. DOOR aggregates door-to-door costs and travel time;
6. TRIPER computes daily trips between zones;
7. TEMPER distributes trips among the hours of the day;
8. RANDKP computes random numbers; and
9. RGNWDE estimates regionwide transportation performance.

FEEDER models a residential area as a square with one or a group of minor activity centers located at the center of one side of the square adjacent to a line-haul corridor. Measures of transit performance are calculated for trips from the interior of the square to the minor activity center. Service options are divided into four categories: (a) direct, (b) subscription, (c) demand responsive, and (d) route based (see Figure 2). Methods for the analysis of these service types are described elsewhere (1-3).

Direct services, such as automobile, bicycle, and walking, are characterized by direct movement from origin to destination. The distance traveled is the rectilinear distance along the streets.

Subscription services, such as carpool and vanpool, are characterized by a collection phase, a line-haul phase, and a distribution phase. The vehicle may be parked in the destination area to await a return trip, or it may be returned to a residential area to collect another load.

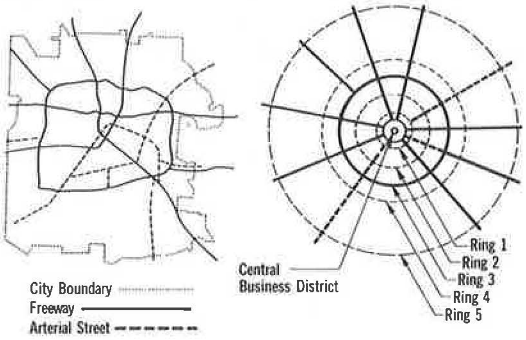
Demand-responsive services, such as dial-a-ride and shared-ride taxi, have three principal modes of operation: (a) many to one, (b) many to few, and (c) many to many. Experience with demand-responsive services indicates that the most common mode of operation is many to few. It is this mode that is represented in the SMART model.

Route-based services, such as conventional bus and light rail, are characterized by regular or semiregular route patterns. Routes can be fixed or flexible with point or route deviation. The fixed-route structure extends from the minor activity center across the residential area. Routes are located symmetrically so as to require the same maximum walking distance everywhere in the residential area.

DUMPER models major activity centers—CBDs, airports, universities, and other employment or commercial centers. If the destination module is the CBD, DUMPER accumulates traffic volumes and estimates congestion delays by using Smeed's equation (4). Vehicles that park in an activity center are charged a parking fee that is divided evenly between entering and leaving trips.

Three categories of travel in the major activity center are examined: (a) street vehicles, (b) fixed-guideway vehicles, and (c) walking. Street vehicles include automobiles, vans, buses, and commercial

Figure 3. Development of circular structure of CBD and major regional travel corridors.



vehicles. Most of these vehicles provide collection and distribution for interarea trips. In addition, there is an intra-area bus service. Fixed-guideway vehicles included light rail and automated-guideway transit. In major activity centers, these vehicles always operate on exclusive guideways. Light-rail characteristics are dictated by station spacing within the major activity center. Automated-guideway services in major activity centers can use any of six route configurations. Walking plays an important role in travel in the major activity center. Many travelers prefer to walk from line-haul interchanges to their activity center destinations. The SMART model assumes that all travelers whose destinations are within 0.4 km (0.25 mile) of an interchange will walk.

LINKER models line-haul movements on high-speed corridors or major arterial streets. Performance measures are computed for the line-haul portion of the trip. Speeds in highway line-haul corridors vary with the volume of traffic carried. Line-haul corridor analysis requires, therefore, that traffic volume data be provided from the regionwide trip distribution or from another source. Traffic volumes can change from hour to hour. The SMART model deals with expected, traffic-influenced speeds. It does not treat phenomena of traffic flow that accompany instantaneous excessive demands, nor does it deal with the queuing problems associated with congested access and egress.

Line-haul-corridor services include (a) mixed-traffic highway services; (b) preferential highway services; and (c) fixed-guideway services. Mixed-traffic highway services introduce transit vehicles into the general traffic that moves along highway corridors of all types. The traffic mix includes automobiles, carpools, vanpools, subscription buses, and conventional buses. Passengers either enter line-haul corridors on vehicles that originate in other modules or transfer to line-haul vehicles at access points. No waiting time is assigned to passengers who do not change vehicles. Waiting times for passengers who board at access points are calculated in one of two ways: (a) half of the line-haul vehicle headway for uncoordinated services or (b) 5 min where feeder and line-haul services have coordinated schedules. Transfers are assumed to take place in well-designed stations or terminals so that the transferring passenger merely needs to walk across a platform to make the change.

Preferential highway services introduce transit vehicles onto exclusive lanes that are set aside for one or more line-haul-corridor services. The exclusive lane is available for both transit and paratransit services, including conventional buses, vanpools, carpools, and others. Fixed-guideway vehicle performance is influenced by station spacing, mean speed between stations, station dwell time, vehicle capacity and headway, and by the technical characteristics of the individual system.

Regionwide analysis accumulates results from all of the modular analyses and aggregates these data for the region as a whole. Unlike modular analysis, which considers many different public transit modes for the same service, regionwide analysis combines the results from an explicit set of modular services to yield regionwide performance. The regionwide analysis requires a complete trip table for the region. Trip tables from comprehensive planning studies can be used, or a trip table can be generated by the SMART model from a general table such as one might find in the Urban Data Book (5) of the U.S. Department of Transportation.

USER OPTIONS

In addition to selecting the characteristics of modules and line-haul corridors, the user of the SMART model can introduce a variety of other options into the model. Some of the more important options are (a) minimum level of transit service, (b) extent of transit service coordination, (c) labor assignment constraints, (d) time-related traffic distribution, and (e) transit mode share.

Because no good methods exist for estimating system ridership, particularly for novel systems and system combinations, the SMART model does not make any attempt to estimate ridership. Rather, the user can introduce eight transit mode shares for consideration. The SMART model will make modular, door-to-door, and regionwide travel calculations for each mode share. The output will also help the user to answer such questions as the following:

1. What are the implications of mode share for the level of operating subsidy?
2. What mode share is needed to justify the desired set of services?
3. What are the impacts of mode share on opportunities for transit integration?
4. What is the impact of different mode shares on traffic congestion?

Transit mode share can also be varied between peak and off-peak periods.

MODEL VERIFICATION

The subprograms for residential area, major activity center, and line-haul corridor were tested against a large number of transit operations. In each instance, the SMART model results can be judged to come from the universe of operating data. Both Student's t and Kalmogorov-Smirnov tests were used at a 5 percent level of significance. Future verification is planned for entire urban areas to test both the application of the SMART model and the accuracy of the results.

REGIONWIDE REPRESENTATION

A regionwide structural representation, shown in Figure 3, is prepared from maps, aerial photographs, census, and other demographic data. The analyst begins by identifying the CBD and the major transportation corridors in the region. These corridors are then represented in terms of a circular structure that has the same area, population, employment, and kilometers of freeways and arterial streets as the urban area (Figure 3). Radial routes can have any angular relation to one another. Urban representations need not be complete circles. Lakes or harbors can be represented by assigning zero population and employment. Discontinuities can be introduced into corridors to reflect rivers or other geographical barriers. Once the corridor structure is established, residential and major activity center modules are identified and located on the circular structure. The product of the representation work is an urban structure that can be entirely or partially analyzed by using the SMART model.

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Discrete Optimization in Transportation Networks

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In most cases, planning capital investment in transportation networks is an unwieldy job because the number of investment options grows so rapidly. The real situation faced by the transportation planner is, in general, when, where, and by how much to allocate available resources. The transportation investment problem can be characterized as the location and timing decisions to be made by the planner. A branch-and-backtrack algorithm is presented that tackles both location and timing aspects of the capital investment problem in small and medium transportation networks. The results presented are encouraging for future research in which the technique can be applied to larger, actual transportation networks.

The problem addressed in this paper is a common one in transportation planning. Given an existing network of M links, a set of future supplies at each origin in the network, and a set of future demands at each final destination, when, where, and by how much should additional investment be dedicated to each link?

For the purposes of this paper, a link can be either a physical connection between two geographically separated points, such as a rail line or a big highway, or it can be a transshipment facility such as a port. It is assumed that demand at each destination and supply at each origin are inelastic—that is, independent of transportation cost. Under this assumption, minimization of present-value social costs aggregated over the network is consistent with maximum national income, and this is the objective function used throughout. The algorithm presented can be extended to price-sensitive supply and demand without computational difficulty by using Devanney's method (1) and replacing cost minimization with maximization of the present value of the sum of the consumer's and producer's surplus. It is also assumed that, whatever the investment, all links are priced at their marginal social cost. In the transportation planner's vernacular, "system-optimized" rather than "user-optimized" operation is assumed. This is in part a reflection of my interest in freight rather than in passenger transportation and in part a reflection of my philosophy that, wherever the results of user-optimized operation differ greatly from those of system-optimized operation, the costs of administering a marginal-cost toll system on nonurban networks can and should be borne.

Finally, it is assumed that future growth of demand and supply is known with certainty. Before we can tackle uncertainty, we must have an efficient algorithm for handling investment with certainty (2). Indeed, one of the goals here is an algorithm that is efficient enough to be routinely run over a range of hypotheses for growth of demand and supply.

Even given all the assumptions above, the magnitude of the problem can be appreciated by considering a network with M links, T possible investment periods, and N possible levels of investment on each link in each period. Then the number of possible investment strategies is N^{MT}. Consider a very small network with four links, three levels of investment on each link, and five investment periods. The number of potential investment strategies is 3.5×10^9. To solve such a problem, for each such investment strategy examined one must

1. Compute the set of equilibrium flows in the network for each period and present value and the resulting link flow costs and
2. Combine the present-value flow costs with the present value of the fixed costs associated with this investment strategy.

In short, each investment strategy examined requires the solution of T network flow problems. Even with the very efficient available algorithms for network flow, direct enumeration of all investment strategies is clearly out of the question for even a very small network.

The major reason that our problem is so different is that we have combined allocation in space with allocation in time. Most work on investment across links has assumed only a single possible investment point in time. Either an investment in a link is made at that time, or it is never made. In reality, given the generally continuous growth in transportation demand, investment timing is as important as investment location. Yet most work on investment scheduling has assumed a network that consists of a single link. This clearly is of little use in determining which of a number of competing links should receive the planner's attention. In short, in many real-world cases, both the location and the timing of investment are crucial. Furthermore, these two dimensions are so closely coupled that, unless they are handled simultaneously, seriously misleading results can be obtained.

The algorithm discussed in this paper is derived from the branch-and-bound technique. Because of its specific branching procedure, it is called in the literature the branch-and-backtrack method. Computational results of tests on several small networks are presented. Although the sample of test results is small and computation time can be very sensitive to the specifics of a particular problem, it appears that the algorithm can efficiently handle the dimension of timing of capital investment. In addition, even if the algorithm must be cut off before optimality, it results in a feasible solution that can then be compared with the best that has been obtained by other means, including the intuition of the network designer.

DESCRIPTION OF THE PROBLEM

The problem can be briefly described as follows:

1. At each of T time periods indexed by t and for each of I origins indexed by i and each of J destinations indexed by j, there are a given demand $D_i(t)$ and supply $S_j(t)$.
2. In addition, there are M different links (actual or potential) in the network that connect the I origins to the J final destinations. On each such link, there are N possible levels of investment. Associated with each possible level of investment on each link is a fixed investment cost $F_m(n)$. This fixed investment cost should include not only the initial cost of the improvements to the link but also any future maintenance costs that are independent of the level of flow on that link present-valued back to time of investment. In addition, there are the flow-dependent costs $V_m(x_t, n_t)$ in each period t, where x_t is the level of throughput on link m and n is the level of investment already in place in that period.
3. Finally, we are considering an overall time horizon of T periods indexed by t. Investment on any link may occur at the beginning of each of the periods. Whatever the level of investment is in each link at each period, it is assumed that the network is operated so as to minimize the total flow-dependent cost of satisfying the given demands from the given supplies in that period. This is also the short-run equilibrium set of flows under textbook competition, such as that observed in the world tanker network. Our problem is to compute the investment strategy—$n_m(t)$, the level of investment in each link in each time period—that minimizes the sum of the present-valued fixed cost of the network and the present-valued flow-dependent costs of operating the network under the chosen pattern of investment.

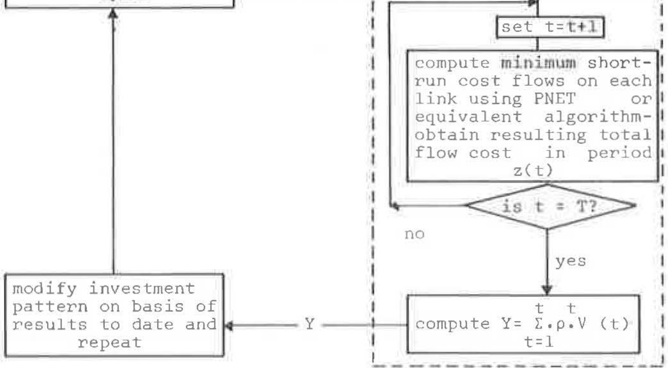


Figure 1. Overall decomposition into fixed investment decisions and short-run operating decisions.

The first step in tackling such a problem is to separate the fixed investment decisions from the resulting short-run flow patterns. For any trial investment pattern $n_m(t)$, the problem of determining the resulting set of short-run flows for each time period t is a simple network flow problem for which a number of extremely efficient algorithms exist. One of the most efficient algorithms—some would argue the most efficient—is the University of Texas primal algorithm PNET (3), which is used in this study. For a given investment pattern in both space and time, it is a relatively straightforward problem to apply PNET to the network T times and determine the minimum flow-dependent costs in each period and the present value. This process can then be repeated for other trial investment patterns. The overall scheme then can be shown as it is in Figure 1.

This basic decomposition makes a great deal of computational sense in that it separates the overall problem into two parts, one of which can be solved very easily. In addition, it represents a natural separation from an economic point of view, dividing the problem as it does into its short- and long-run components. Such an explicit treatment of the short run allows us to model demand growth and, among other things, generates the optimal tolls on each link in each period for each investment pattern studied. These tolls will appear as the duals associated with the corresponding link variable cost function. If one is unwilling to assume one has direct control over the network operations or the ability to levy congestion tolls, then the actual short-run flows will be user optimized. The basic decomposition can still be used to generate "second-best" investment patterns. In so doing, one would use one of the network flow algorithms that generate user-optimized flow patterns to simulate the network in each period. From this flow pattern, one can compute the corresponding flow-dependent social costs and then proceed as before.

Transportation investment by its nature tends to come in large, discrete chunks. It simply does not pay to add half a lane to a highway or half to a port. Given such indivisibilities and a continuous growth in transportation demand, even under an optimal investment pattern, individual links will almost never be operating at design capacity. At any given point in time, some links will be operating below design capacity and some above. Hence, analysis that assumes such an unattainable long-run equilibrium will not only yield misleading results with respect to investment but will also yield no results as to how the network should be operated and priced through time. A more complete discussion of the coupling between long-run investment and short-run pricing, given indivisibilities in capital investment, is presented by Devanney (1).

The real problem lies in the left-hand side of the diagram in Figure 1—that is, in the method for choosing the investment patterns to be costed out. We have already seen that direct enumeration of all possible investment patterns is clearly infeasible because of the number of such alternatives. Two basic approaches that use the decomposition of Figure 1 have been suggested: (a) Bender's decomposition, which at each iteration of the left-hand portion of Figure 1 generates an integer problem, and (b) the branch-and-bound technique. The method examined in this paper is a variant of the branch-and-bound technique. A comparative effort at the Massachusetts Institute of Technology (MIT) is studying Bender's decomposition.

Several authors have applied branch-and-bound to capital investment in transportation networks. Perhaps the most significant work for our purposes is that of Ochoa-Rosso (4), who in 1968 presented formulations for four different transportation problems. All of those problems, however, dealt with the static problem and used a single target year. Ochoa-Rosso did not deal with the problem of multistage improvement—the scheduling dimension—but only cited it as a potential field needing further study. He used the bound criteria previously used by Ridley in 1965. In essence, the formulations presented by Ochoa-Rosso and later by Tan (5) assume that the planner has the option to perform a single investment now or reject it completely.

Ochoa-Rosso and Silva subsequently applied one of Ochoa-Rosso's formulations in a case study on the Puerto Rico system of seven nodes and four links (6). They assumed one target year and applied two methodologies—branch-and-bound and branch-and-backtrack (a variation of branch-and-bound with a different branching sequence)—to select the optimum choice out of 16 possible alternatives. There do not appear to have been any significant improvements in the application of branch-and-bound to transportation network investment since Ochoa-Rosso's work.

BRANCH-AND-BACKTRACK METHOD

Key Assumptions

To solve the network investment problem outlined above by branch-and-bound, it is necessary to make two basic assumptions about the form of the flow-dependent cost functions on each link.

The first assumption is that the variable flow-dependent cost on each link does not increase with the amount of investment committed to each such facility. In other words, as the investment level in a transportation link increases, the variable cost associated with handling a given amount of traffic decreases. Still more concisely, it is assumed that the partial of all link flow-dependent cost functions with respect to link investment is nonpositive: $[\partial VC(x,I)/\partial I] \le 0$, where VC (x, I) is the variable cost associated with an investment level I and a flow of x. This hypothesis is not particularly limiting. In general, this is the situation for the bulk of transportation facilities. If the planner of a roadway invests to provide two lanes, the variable cost associated with a certain level of traffic will be higher than the variable cost associated with the same level of traffic if the road had four lanes instead. This will certainly be true for all but very low levels of throughput.

Another typical example would be the level of investment in a road in terms of the construction material. As long as the quality of material to be applied on the surface of the road is increased, the variable cost associated with a specific level of traffic will be the same as or less than the cost that would have resulted from investing in a cheaper, lower-quality pavement (see Figure 2, where F_i = fixed cost associated with investment i, q = traffic flow, and h = variable cost).

For traffic flow q′, the variable cost is the same, independent of the fixed costs. For q_1, the variable costs for investments I_2 and I_3 are the same but the variable costs for I_1 are higher. The same thing happens for q_2 and q_3.

The second basic assumption is even less controversial. Assume that the partial of the flow-dependent link cost functions with throughput is nondecreasing: $[\partial VC(x,I)/\partial x] \ge 0$. The partial is generally called the marginal social cost. For most transportation technologies, this marginal unit is constant or nearly so at low levels of throughput and increases rapidly as throughput approaches and passes the design capacity of the task (see Figure 3, where MC = marginal cost). Independent of the level of investment, as traffic flow increases from q_1 to q_3, the marginal associated cost will first be constant and then, as the flow approaches capacity, its value will abruptly increase.

In any event, these two rather weak and generally realized assumptions are the only requirements in the functional form of network costs that must be improved so that the branch-and-bound algorithm can be used. All sorts of functions are possible within this general framework, including economies and diseconomies of scale with respect to investment.

Example

Consider a single-period problem that involves three links, for each of which low, medium, and high levels of investment are possible. Assume further the sets of costs given in Table 1 by level of investment and link. Note that the link flow costs decrease with increasing investment, as required by the algorithm.

The problem can be represented by a decision tree such as that shown in Figure 4. The left-hand three-way branch represents the decisions for link 1. Whatever is decided for link 1, we are then faced with the decision for link 2. This three-way choice for each possible link 1 decision is represented by the second set of branches on the tree. Finally, the link 3 choices are represented by the right-hand set of branches. There are 27 terminal nodes to the tree, representing the 3^3 possible patterns of investment. The number in parenthesis at the tip of each right branch in Figure 4 represents the order of evaluation as the algorithm proceeds. More detail about the algorithm can be found elsewhere (7).

APPLICATION OF TECHNIQUE TO TRANSPORTATION NETWORKS IN VENEZUELA

Caracas Transportation Links

Problem

The branch-and-backtrack algorithm was tested on a very simplified version of a transportation investment problem that currently faces Caracas, the capital and largest city of Venezuela. Caracas attracts commodities from the inland and from abroad as well. As the most developed city in the country, Caracas also provides the rest of the country with products manufactured by its industries, some of which are also exported.

Since Caracas is located 12 km (7.5 miles) from the seashore, all exports and imports currently travel over a single highway that links Caracas to the nearest port, La Guaira. The road was built in 1952 as a two-lane, two-way highway and was later widened to a four-lane, two-way highway and was later widened to a four-lane, two-way highway. Another important characteristic of the geography of Caracas is that the city is about 939 m (3100 ft) above sea level. The mountainous route between Caracas and La Guaira has two two-way tunnels and two two-way bridges, each of which is about 970 m (3200 ft) long.

Traffic on the system is currently congested, particularly at peak hours. Aside from the import and export traffic, local goods destined for various parts of the Venezuelan coast (cabotage) as well as traffic to and from Venezuela's only international airport at La Guaira contribute to the demands on the road.

The problem faced by planners in Caracas is how to improve the transportation system so as to avoid future congestion. Their options include investment in the road to increase its capacity, investment in the La Guaira port to improve the service capacity provided there, and the construction of a new rail system to link Caracas with Puerto Cabello, a port about 121 km (75 miles) away. In connection with the construction of this new rail line, the Caracas planners must also decide on the amount of investment that is required to make Puerto Cabello a feasible alternate port to La Guaira (see Figure 5).

In essence, this represents a typical investment problem in which there are four possible transportation links: the Caracas-La Guaira road; the port of La Guaira; the Caracas-Puerto Cabello rail line; and the port of Puerto Cabello. Although it is simple, such a transportation network can be used to test the applicability of the previously developed branch-and-backtrack technique in investment decisions. More details about the cost model used in this example can be found elsewhere (7).

Figure 2. Total investment costs.

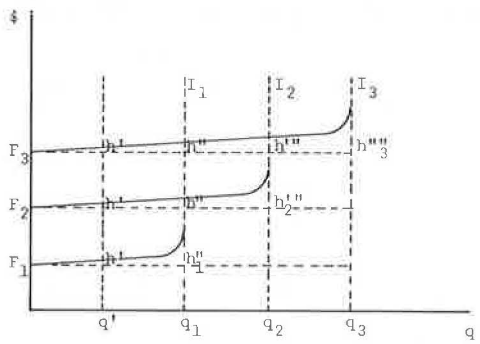


Figure 3. Total investment and marginal costs.

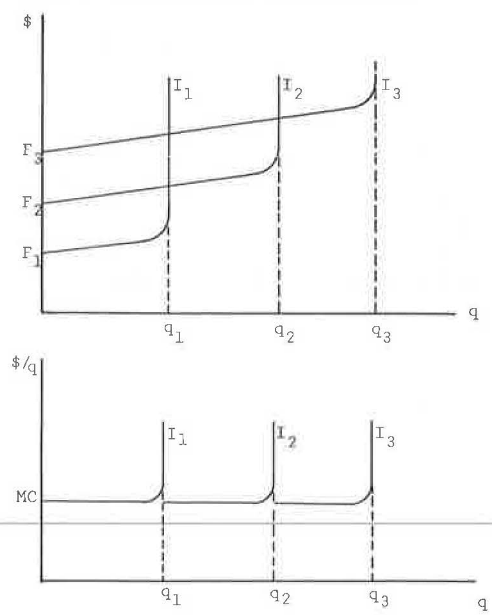


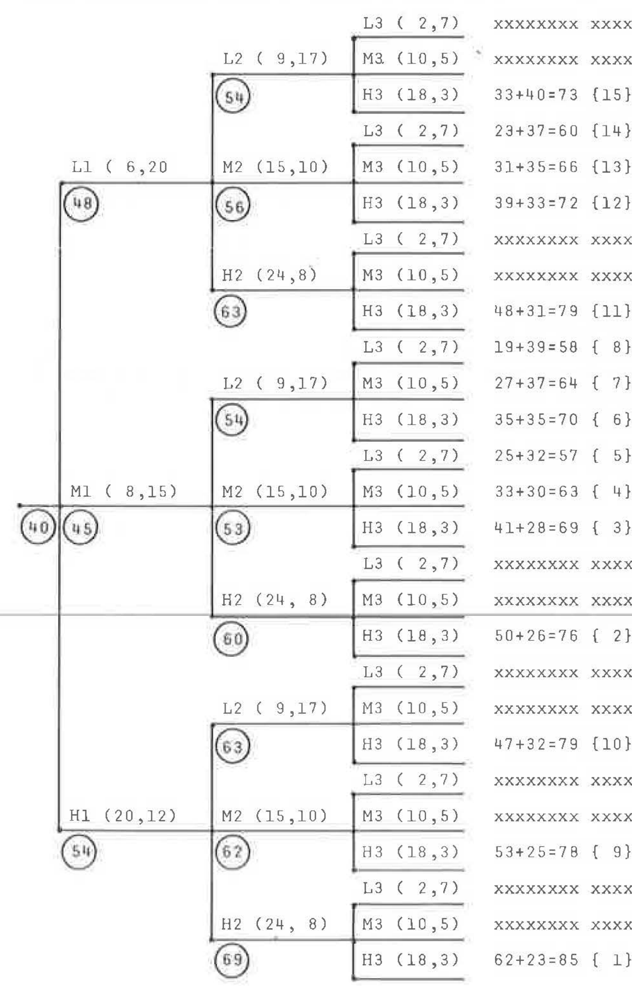
Table 1. Investment and flow-dependent costs for three links and three levels of investment.

Link	Fixed Costs			Present-Value Flow Costs		
	Low	Medium	High	Low	Medium	High
F_1	6	8	20	20	15	12
F_2	9	15	24	17	10	8
F_3	2	10	18	7	5	3

Results

It was assumed that the Venezuela planners would determine the optimal investment policy in 1959 and then, assuming no disinvestment for the subsequent years, would at discrete points in time (say, years) search for new investment plans from that point on to improve the previously determined option. Thus, in the initial tests we did not attempt a true optimization over the time dimension but a series of suboptimizations in

Figure 4. Example of branch-and-backtrack method.



which, at any point in time, the transportation planner could make a particular investment "now or never". Thus, the total number of possible investment patterns was 625×10 rather than the true 625^{10}.

Five different problems of this sort were run with randomly varied coefficients, and the results are given in Table 2. For the five cases given, the common information shown in Figure 4.4 of the report by Lago (7) was assumed. Furthermore, the link characteristics associated with each investment set, such as handling rate (for each port), road capacity and operating cost, and rail capacity and operating cost, were varied.

Two comments should be made about this set of suboptimizations. In 1959, Venezeula planners are assumed to be faced with only the 625 immediate investment options. After the given number of iterations, they obtain their answer for 1959. In 1960, the same planners, under the restricted ground rules of this test, are faced with the same problem but given the investment that has already been made. This procedure is then repeated for each of the remaining years. The last five computations, given in Table 3, show the cost involved.

The algorithm was developed and run on an IBM

Figure 5. Caracas rail and road links.

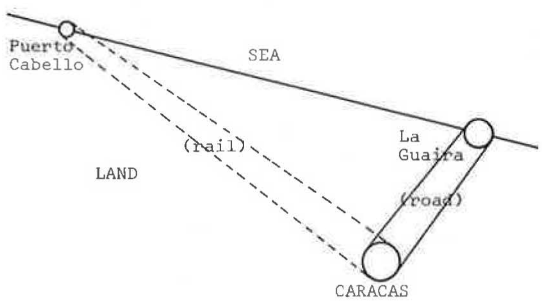


Table 2. Initial suboptimization runs for Caracas transportation links.

Case	Number of Links	Number of Investments on Each Link	Total Number of Investment Patterns	Number of Iterations	Number of Evaluations Performed
1	4	5	6250	29	140
2	4	5	6250	18	173
3	4	5	6250	133	214
4	4	5	6250	76	140
5	4	5	6250	117	164

Figure 3. Computations for Caracas problem showing cost of execution.

Case	Number of Facilities	Number of Investments	Total Number of Iterations	Number of Evaluations Performed	Cost of Execution ($)
1	4	5	6250	158	0.76
2	4	5	6250	150	0.71
3	4	5	6250	95	0.61
4	4	5	6250	109	0.79
5	4	5	6250	6250	12.27

Table 4. Final computer runs for Caracas problem.

Case	Number of Periods	Number of Possible Investments at Each Period	Total Number of Investment Patterns	Number of Evaluations Performed	Cost of Execution ($)
1	10	16	1×10^{12}	16	0.47
2	10	16	1×10^{12}	385	1.38
3	10	16	1×10^{12}	7196	26.55

370-168 computer at the MIT Information Processing Center. Figures given include central processing unit, memory, and input-output (I-O) cost but not setup and print charges.

Unfortunately, we did not keep a record of the exact modifications established for the first, second, and fourth cases. It appears that sometimes only the demand schedule was changed and at other times the link characteristics were changed. In the last computation, the system was "forced" to evaluate all possible investment alternatives through its lifetime—i.e., 625 evaluations at each decision or 6250 evaluations. The resulting execution cost gives an idea of the economy that can be achieved by using the branch-and-backtrack algorithm.

On the basis of these encouraging results, it was decided to try to solve the investment scheduling problem in a truly optimal fashion. Another trial was therefore conducted to verify the practicability of the method (see Table 4). At each decision point, four facilities and two levels of investment were assumed so that there were 16 alternatives open to the planner and, in the 10-year life, 16^{10} or 1.1×10^{12} options. In these three cases, the basic information given in the Lago report (7) was assumed. The magnitudes of investment were changed in the first two cases in such a way that the first values were half of the second values. It is worth considering the great sensitivity in terms of the number of performed evaluations that is apparent whenever the investment level is increased. For the third case, although the optimum solution has not been reached, the best feasible point up to that printing limit is obtained. Thus, a good result is obtainable by use of the algorithm even under computer-time or budget constraints.

Given that the proposed algorithm evaluates the vector of the highest investments as its first point in the tree, if the associated fixed costs are not significant in comparison with the total cost, then this point is closer to the optimum one. In such a case, solutions are obtained in few iterations (cases 1 and 2 in Table 4). On the other hand, if fixed costs are very large in comparison with total costs, then the actual optimum will be much farther from the initial solution and it will take the algorithm a great deal longer to come up with the optimum (case 3). Once again, we see the importance of a good initial solution and the role of the transportation planner's judgment.

Venezuela Transportation Network

Problem

On the basis of the preliminary but rather encouraging results discussed above, it was decided to apply the proposed branch-and-backtrack algorithm to a larger, more realistically sized transportation network. To exploit the information already obtained in the Caracas case, we decided to analyze a simplified transportation network in Venezuela.

The first problem was to characterize the Venezuela transportation network in 1959, the year for which cost information was available. This proved to be impossible. A scenario was therefore hypothesized for 1959. This assumption did not defeat the purpose, which was to test the validity of the proposed algorithm for a dynamic situation in a medium network.

The problem is presented schematically in Figure 6. Twenty-two cities were selected, and 48 transportation facilities were defined. Each arc in the figure represents one facility and each node the city of transshipment. It was assumed that in 1959 the Venezuela transportation network had basically two modes of trans-

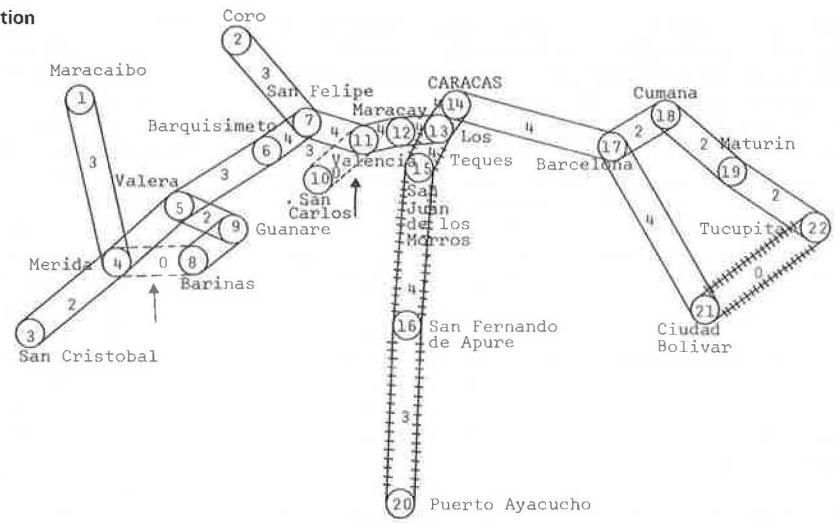


Figure 6. Representation of Venezuela transportation network for analysis of investment problem.

Table 5. Computer analysis of investment problem for simplified Venezuela transportation network.

Case	Number of Facilities	Number of Investments	Number of Iterations	Number of Evaluations Performed	Cost of Execution ($)
1	5	27	1.4×10^7	27	3.00
2	5	27	1.4×10^7	40	3.38
3	5	27	1.4×10^7	51	3.55
4	5	27	1.4×10^7	385	17.65

portation—road and rail. Although the country has navigable rivers, no data on water transportation were available, and so it was eliminated from consideration. To simplify the transportation investment problem, it was also assumed that only internal movements within Venezuela were being studied. Except for the broad view of costs, the problem has all the same characteristics, in terms of investment, costs, etc., as the previously described Caracas case.

Two railroads were considered (Figure 6): the one from Los Teques (13) to Puerto Ayacucho (20) and the one from Barcelona (17) to Ciudad Bolivar (21). All other facilities were assumed to be roads. For each facility, one level of capacity was arbitrarily assigned (see the numbers inside the arcs in the figure). Thus, whenever potential investments were analyzed, there was a basis for evaluating possible capacity improvements.

Three potential locations for the construction of new transportation facilities were hypothesized (a) a road from Merida (4) to Barinas (8), (b) a road from San Carlos (10) to Valencia (11), and (c) a railroad from Tucupita (22) to Ciudad Bolivar (21). Three levels of investment (low, medium, and high) were also hypothesized for each of the above facilities. The period of analysis was assumed to be five years. Thus, at each decision point in time there were 3^3 or 27 possible combinations and, through all five years, 27^5 or 1.4×10^7 investment strategies to be studied.

For this problem, we selected the mathematical programming system for solving network flow problems, PNET. This system was easily incorporated in the algorithm as a subroutine of calculation. In each evaluation, this equilibration procedure was used and it was assumed that the demand-supply pattern was inelastic (if desired, this assumption can be relaxed).

Results

The investment options used (7) represent the investment values faced by the planner at each period of time. In addition, a unit cost of transportation, besides the upper and the lower bounds, was associated with each link. The results obtained are given in Table 5 (the last case was interrupted by the limit on computer time).

The same level of investment was assumed at each decision point. Associated with these fixed costs were various link characteristics such as capacity and operating costs. Furthermore, each link on the network had a fixed unit cost and upper and lower bounds. For supply and demand schedules, it was assumed that at each period one origin point supplies one particular value and one destination point demands another fixed value.

CONCLUSIONS AND RECOMMENDATIONS

1. The results obtained for the Caracas problem were encouraging. The capital investment aspects of location and timing decisions were tested, and feasible solutions were found at reasonable expense. The major finding is that in most cases the aspect of investment timing can be jointly analyzed with location and that this can be done within a reasonable range of work. Both small and medium transportation networks were examined under multistage investment decisions, and feasible solutions were obtained.
2. Both of the problems examined show that, by using the proposed algorithm, the planner should come up with a very good solution within assumed budget constraints.
3. The planner's initial feelings should be incorporated in the algorithm to save many extra computations before convergence toward the optimum solution. This is verified in the example shown in Figure 4: Depending on each investment assumed for link 1, different costs are found in obtaining the optimum result.
4. The Caracas problem illustrates the feasibility of running the branch-and-backtrack algorithm under different conditions. Let us say that five demand schedules that cover a reasonable range are hypothesized. This would give a good idea of possible strategies to be selected by the planner.
5. As a result of observations made during the running of the Caracas problem, it was concluded that, whenever more constraints are presented in the sys-

tem, fewer iterations will be performed before the optimum solution is reached. It would be advisable to incorporate, let us say, budget constraints to be faced by the planner at each decision point.

6. Both problems analyzed present completely different structures. The first concerns a small network, and the user-optimized rule is used for network equilibration. The second concerns what can be regarded as a medium network, and the equilibration procedure used is the system-optimized rule. The proposed algorithm could be applied in both cases. This illustrates its versatility.

7. As Ochoa-Rosso (4) points out, more research should be devoted to the study of the trade-off between the branch-and-bound and branch-and-backtrack methods. Although the first requires greater computer memory, the second is more time consuming. This needs to be verified.

8. The technique proposed here for capital investment problems should be compared with another optimization procedure such as the Bender method.

ACKNOWLEDGMENT

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*P. A. R. Lago was a graduate student at the Massachusetts Institute of Technology when this research was performed.

Residential Area Location Preference Surfaces

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Although an understanding of the interaction between land use and transportation is essential to a rational evaluation of urban and regional policy, it is frequently complicated by the introduction of sophisticated mathematical techniques. In an effort to make this interaction more visible to the decision maker, two of the more advanced techniques—multinomial logit analysis and mental maps—are placed in a common framework of analysis and presentation. The strength of a rigorous theoretical background is thus combined with the simplicity of a visual presentation. The theory and development of the technique are outlined, and its use in a case study of the residential location preferences of residents of the inner suburbs of Melbourne, Australia, is described.

An understanding of the ways in which transportation investment, activity placement, and residential location interact is essential to a rational evaluation of urban or regional policy alternatives. Frequently, however, the methods used by planners to examine these interactions are complicated by the introduction of sophisticated mathematical models. Although such models may improve the explanatory power of the planning method, such an improvement is frequently made at the expense of the layman's understanding of the method.

If one wishes to make the interactions clearly visible to the decision maker, who frequently is not aware of the mathematical complexities involved in the modeling process, a clear, concise method for the presentation of results and implications must be devised. This paper attempts to provide such a method and at the same time to use two of the more advanced mathematical techniques in the analysis of location decision: multinomial logit choice modeling and the concept of mental, or cognitive, maps.

The approach, which is shown schematically in Figure 1, has essentially three stages. In this paper, the model is developed in the context of urban residential location. However, the basic model structure, as outlined in Figure 1, could well be applied to problems that involve regional development policies, decentralization, or alternatives of facility location.

THEORY OF CHOICE

A great deal of research in the areas of economics and psychology has been devoted to establishing a general theory of choice. Although many of the results have been conflicting, several general themes permeate all modern theories of choice.

First and foremost is the concept that all choice decisions are probabilistic. This implies that a decision outcome can never be inferred with certainty. All that one can do is to assign a probability to that decision. Second, choice decisions are not made between alternative objects but rather between the alternative sets of characteristics that those objects possess. This idea is expressed in the economic literature in Lancaster's new approach to consumer theory (1) and in the psychological literature in Rosenberg's cognitive summation theory of attitude (2).

Beyond these common principles, however, there are a large variety of methods that link the characteristics of an object with the eventual choice of that object. One basic component of psychological models of choice that is not generally found in economic choice models is the realization that the choice process is composed of three separate but interrelated phases. Such a general choice model, described by Golob and others (3) and Levin (4), is shown in Figure 2.

Economic theories of choice generally do not account for the second phase of the model, i.e., the subjective assessment of the decision maker and the alternatives; rather, they assume, or at least imply, that the choice behavior of a decision maker is directly related to his or her objective socioeconomic characteristics and to the objective physical characteristics of the alternatives. On the other hand, psychological theories of choice not only recognize but also stress the overriding importance of the subjective transformation of the characteristics of both the decision maker and the alternatives.

As important as the recognition of the three phases of the choice process is realization of the links between elements of the three phases. In their discussion of a model structure similar to that shown in Figure 2, Golob and others (3) have highlighted many of the important links. Although they show all of the links in Figure 2 to exist, the relative strength and importance of such links is believed to differ. Golob and others conclude that the most important link is that between the characteristics of the choice alternatives and the perceptions of those alternatives. Thus, the decision maker's subjective impressions of the characteristics of the alternatives are critical in the overall choice process. Although a characteristic may, in reality, be changed, that change will not affect the choice decision unless the perception of the characteristic also changes. Thus, neither minor changes that go unnoticed nor relatively major changes that simply do not come to the attention of the decision maker will affect choice probabilities. On the other hand, choice probabilities can be changed without changing the alternatives if one can instead change the perceptions of those alternatives—for example, by information dissemination, advertising, or propaganda. Thus, an understanding of the choice process as a three-phase process has important consequences for policymaking and modeling.

From a modeling viewpoint, this process requires that, instead of using objective measurements of characteristics in a model, one must first obtain subjective interpretations of such characteristics. In some circumstances, this is inevitable since it is impossible to obtain completely objective measurements of a characteristic (e.g., comfort or convenience in a mode-choice decision); but it also requires that, even when objective measurements such as travel time are obtainable, one must still transform the objective measurement into a subjective impression before using it in a model. For example, is a 20-min trip really regarded as being twice as time consuming and burdensome as a 10-min trip?

MENTAL MAPS

Important as subjective transformation is in the choice process, relatively little work has been performed to indicate the nature of such transformations in the context of mode-choice modeling (4-6). What work has been done has concentrated on the variation in the perception of a single characteristic for a particular alternative (mode). In the context of spatial choice problems, however, the situation is a little different. Here one is concerned more with the variation in the perception of characteristics over an urban or regional area. Fortunately, a well-established body of literature on this subject is available under the concept of "mental maps" (7).

An individual's perception of his or her environment is molded not simply by the physical environment itself but also by the individual's level of knowledge of that environment. Where the level of knowledge is high, then the real environment and the individual's perception of the environment are likely to be similar. But as the level of knowledge decreases so too does the similarity between the real and the perceived environment, and subjective impressions, generalizations, and biases play an increasingly important role in the formulation of the mental image of the environment. Just as a cartographic map can represent the real environment, so too can a mental (or cognitive) map represent the perceived environment.

The study of mental maps has been formalized in the work of Gould and White (7, 8). In a number of studies of various geographic locations, they considered the environment as perceived by the subjects of their ex-

Figure 1. Basic model structure.

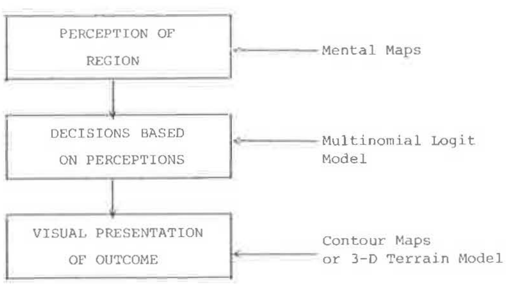
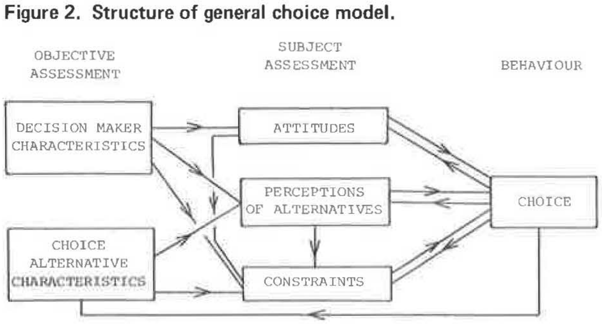


Figure 2. Structure of general choice model.



periments. They considered California school dropouts' impressions of America, British school dropouts' impressions of Britain, a black child's impression of his immediate neighborhood in Boston, and Swedish children's impressions of Sweden, and they found that the mental maps retained by each subject were found to depend basically on the subject's level of knowledge of the area under consideration. The level of knowledge could in turn be expressed in a number of ways. For example, such knowledge may depend on the duration of residence in a certain area, the number of times a place has been visited or traveled through, the proximity of the area under consideration to the place of residence, and the age, education, and background of the respondent.

Previous studies have shown the usefulness of mental maps in describing perceptions of regional areas. Our study differs in three aspects:

1. The study area is a metropolitan urban area. Given the success of the mental-map approach at both the regional and immediate-neighborhood levels, there is no reason to believe that it will not be just as applicable at the intermediate level of an urban area.
2. The charting of mental maps, although of interest in itself, is not the major objective of the study. The mental maps will subsequently be used as input to a modeling process to obtain residential preference ratings.
3. The third point of difference is perhaps the most fundamental. Previous mental-map studies have requested subjects to rate particular geographic locations as, for example, a place to live. It is known, however, that the decision on residential location is not based on a rating of the geographic location per se but on a rating of the various characteristics that describe that location (1). In the light of this recognition that a location is described in terms of its characteristics, it seems reasonable to obtain mental maps of these characteristics in a spatial context as a basic first step to obtaining residential preference indicators.

Obtaining mental maps of area characteristics rather than of geographic areas has several advantages:

1. It enables the respondent to react to specific characteristics rather than to broad classifications such as geographic areas. This feature promises more valid assessment of attitudes and perceptions (4).
2. It enables one to evaluate the contribution of each characteristic to the overall assessment of the area.
3. It gives an indication of the subjects' knowledge of the specific characteristics of an urban area.
4. It enables one to trace the effect of a change in one of the characteristics through to its final effect on residential preference.

A limited attempt to obtain mental maps of characteristics, or categories of characteristics, is described by Gould and White (7) in their discussion of the work of Harris and Scala (9). As will be seen later, our study differs considerably in the way in which the mental maps of characteristics are combined.

Mental maps are traditionally represented as contour maps. They can be represented equally well, however, in the form of a two-dimensional matrix in which the dimensions correspond to the latitude and longitude of the geographic region under consideration and the elements represent respondents' ratings of the geographic area at a particular latitude and longitude. Thus,

$$S = \{S_{ij}\} \quad (1)$$

where S = perceived satisfaction with the geographic region (i.e., a mental map) and S_{ij} = perceived satisfaction with the geographic area at latitude i and longitude j.

Extending this representation to the present study, in which mental maps of characteristics are being considered, one can use a three-dimensional matrix $\{S_{ijk}\}$ to represent a series of mental maps for the characteristics of the area, where S_{ijk} is the perceived satisfaction with characteristic k at latitude i and longitude j. The manner in which this three-dimensional matrix is collapsed into a two-dimensional preference surface will depend on the choice process assumed to exist in the process of residential location choice.

CHOICE PROCESS MODEL

Recent investigations into choice processes (particularly mode-choice processes) have used the theory of individual utility maximization to derive a choice model known as the multinomial logit model:

$$p(a) = \exp(CU_a) / \sum_{b=1}^{N} \exp(CU_b) \quad (2)$$

where

- p(a) = probability of choosing alternative a,
- C = sensitivity coefficient,
- U_a = utility of alternative a, and
- N = number of alternatives.

The utility function U_a is generally assumed to be a linear additive function of the characteristics such that

$$U_a = \sum_{k=1}^{M} I_k \times S_{ak} \quad (3)$$

where

- I_k = importance of characteristic k in the choice process,
- S_{ak} = level of satisfaction with characteristic k for alternative a, and
- M = number of characteristics.

In considering spatial choice problems and recalling the representation of the mental maps of characteristics as a three-dimensional matrix, Equation 3 can be expressed as

$$S_{ij} = U_{ij} = \sum_{k=1}^{M} I_k \times S_{ijk} \quad (4)$$

and subsequently

$$S = \{I_k\} \times \{S_{ijk}\} \quad (5)$$

Equation 5 states that the overall mental map of a region is a weighted sum of the individual mental maps of characteristics for that region. This formulation is a generalization of those of Harris and Scala (9) and McHarg (10) (who used a similar concept for the identification of feasible highway routes). In both of those works, the importance matrix was implicitly assumed to be a unit matrix.

The final step in the development of the area preference surface is to relate the mental map of a region to the probability of choice of subareas within that region. This may be done by combining Equations 2 and 4:

$$p(ij) = \exp(CU_{ij}) / \sum_{b=1}^{m} \sum_{d=1}^{n} \exp(CU_{bd}) \qquad (6)$$

where

p(ij) = probability of choosing an area with latitude i and longitude j,
m = all latitudes, and
n = all longitudes.

CASE STUDY

To test the application of the theory described above, a study was conducted to determine the attitudes and preferences of people who had moved into the region that borders on the central city of Melbourne during the period from August through November 1975. The central-city suburbs of Melbourne are, as shown in Figure 3, South Melbourne, Port Melbourne, Melbourne, Fitzroy, Collingwood, Richmond, Prahran, and St. Kilda.

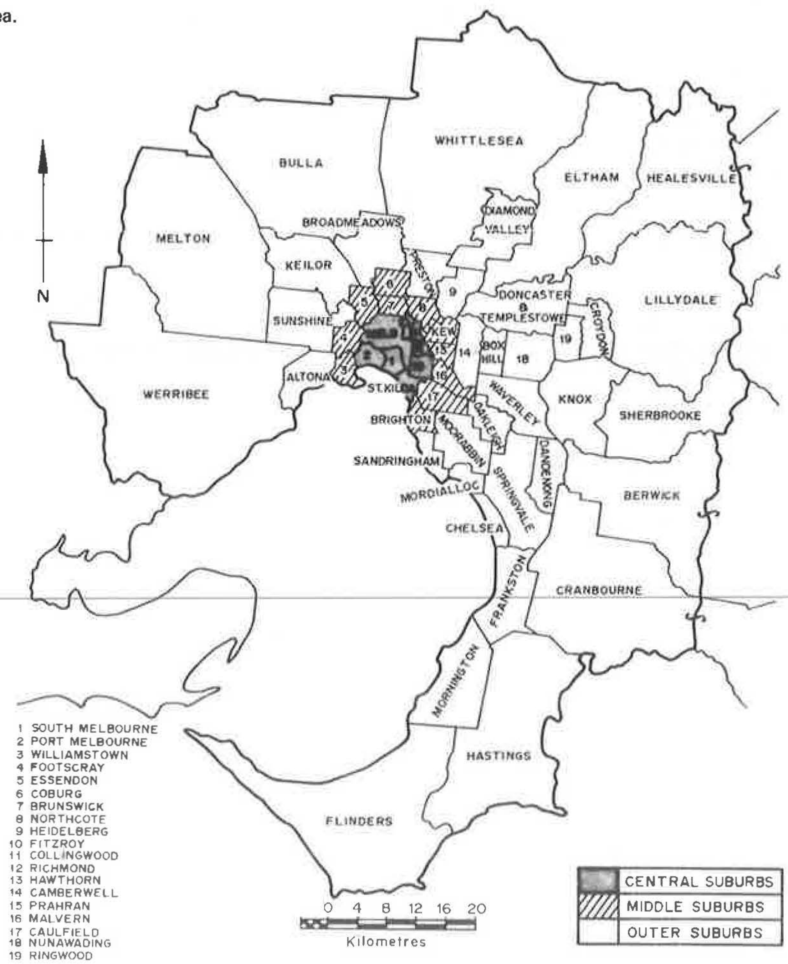
New residents were interviewed as soon as possible after they moved into the study area. This procedure was chosen for two reasons:

1. The respondents had recently made an overt decision to move and so their attitude and actions were likely, at that time, to be closely related.
2. Since all residents in the study had moved at approximately the same time, one could assume that the characteristics describing each area under consideration would be the same for all study respondents.

The study took the form of a home interview questionnaire survey primarily aimed at establishing respondents' perceptions of how well a number of alternate locations would satisfy them with respect to a number of specific factors. The factors considered are given below:

Factor	Key
Closeness to	
Present workplace	Work
Shops	Shops
Public transportation	Transport
Open country	Country
Bay beaches	Beaches
Parks, play areas, golf courses, ovals	Ovals
Entertainment	Entertain
Friends	Friends
Relatives	Relatives
People of same age	Age
People of same social level	Social
People of same nationality	Nationality
Pedestrian safety	Safety
Traffic noise	Noise
Traffic congestion	Congestion
Tidiness of area	Tidiness
How well buildings are maintained	Maintain

Figure 3. Study area.



Factor	Key
How clear the air is	Air
Presence of trees, shrubs, and grass	Trees
Type of housing	Home type
Cost, rent, and value for money	Cost

Respondents were asked to rate, by means of semantic scales, the importance of each of these factors in their choice of residential location. They were also asked, on the basis of each of these factors, to indicate how satisfactory they considered three suburbs: their present suburb plus one each, with which they were familiar, from the middle and outer suburbs.

A total of 261 questionnaires were administered to 244 households. Of these, 122 were renters and 122 were owners of residences. The sample represented 16 percent of renters and 33 percent of owners who moved into the area during the study period.

Mental Maps of Characteristics

Translating theory into practice is usually associated with problems that are resolved by making approximations or assumptions. This study is no exception. It was mentioned earlier that a mental map is a representation of a person's perception of an area. The difficulty in this study was that, as mentioned earlier, not all areas were rated by all respondents. Only three areas (one inner, one middle, and one outer suburban area) were rated by each respondent, and these areas varied from respondent to respondent. Thus, complete individual mental maps did not exist. To obtain the average mental map of new inner-suburb residents, it was necessary to assume that they all perceive the urban area in a similar fashion. Thus, respondent B's perception of a particular area can be substituted for respondent A's perception of that same area when respondent A did not in fact rate the area. The average mental map for all respondents can therefore be obtained by calculating the average rating for each area from those respondents who rated that area and then constructing a composite map of these average ratings. Although this assumption may be severely questioned, it was a necessary step in view of the available data.

Mental maps constructed in this manner are shown in Figures 4 and 5 for two factors considered in the study: closeness to public transportation and closeness to bay beaches. Each map is constructed for the combined group of owners and renters between whom there were no significant differences in ratings.

It can be seen that the mental maps so constructed appear to be reasonably consistent with intuition and knowledge of the Melbourne urban area. The public transportation map shows decreasing satisfaction with increasing distance from the central-city area and from major railway corridors. The bay beaches map, as expected, shows a decreasing satisfaction with increasing distance from bay beaches.

Because of space limitations, it is not possible to include here the mental maps for all factors, but certain general patterns do emerge:

1. A series of concentric rings—Satisfaction with shops, public transportation, and entertainment decreases with increasing distance from the central city, and satisfaction with open country, parks, pedestrian safety, traffic noise, traffic congestion, cost of housing, and cleanliness of the air increases with increasing distance from the central city.
2. An east-west distribution—Generally higher levels of satisfaction were recorded in the eastern than in the western areas for factors such as tidiness of the area, maintenance of buildings, the presence of trees and shrubs, and type of housing.
3. An inland distribution—Satisfaction with bay beaches decreases with distance inland from Port Phillip Bay.

Polynomial Representation of Mental Maps

Although the mental maps, as constructed above, were effective in representing the general distribution of satisfaction with a particular factor, they had three distinct disadvantages. The first disadvantage was the actual distribution of suburbs chosen by respondents. Some suburbs were chosen often for evaluation, whereas other areas did not attract a single response. Thus, the task of interpolating and drawing contour lines in these areas was quite difficult.

Another disadvantage was that the unbalanced distribution of chosen areas also meant that the ratings of some suburbs were obtained from the average of a large number of responses and those of other suburbs were obtained from a single response. If this one response was extreme or atypical, then the resultant mental map showed inconsistencies and discontinuities. Although such discontinuities, or fault lines, are indeed possible (7, p. 191), it was felt that in this study they were more the result of the data than of any underlying intrinsic cause.

A third disadvantage was that, since the mental maps were to be transformed into matrices for use in the modeling process, a simple computer-based process that eliminated the need for tedious hand calculations and contour-map interpolations was desirable.

The solution to these three problems was to replace the hand-drawn mental maps shown in Figures 4 and 5 with polynomial surfaces fitted to the data in the mental maps. The idea is similar to the terrain-smoothing methods used in highway location studies such as GCARS (11). The basic objective of the method is to replace the observed mental map by a polynomial equation in terms of i and j (the coordinates of latitude and longitude within the urban area). This technique has several advantages:

1. It makes interpolation at any point in the urban area very simple by merely requiring the substitution of the i and j coordinates in the polynomial equation.
2. The surface-fitting process automatically gives more weight to suburbs that receive a large number of respondent evaluations and less weight to single-response (possibly extreme rating) suburbs.
3. Expressing mental maps in polynomial form makes it possible to combine different mental maps in simple algebraic steps.

One decision that had to be made was the order of the polynomial to be used. In the GCARS terrain-modeling exercise, little difference was found between polynomials of order six and higher-order polynomials. To determine the order of polynomial to be used in this study, four measures of effectiveness were considered: changes in the residuals, in the correlation coefficient, and in the F-ratio and visual observation of changes in the predicted surface as the order of the polynomial increases. In Figures 6 and 7, variations in the F-ratio and the correlation coefficient are shown for two factors—closeness to public transportation and closeness to bay beaches. It can be seen that, as the order of the polynomial increases, the degree of fit increases but at a decreasing rate and that, as in the GCARS study, increasing the order of the polynomial to more than six does not improve the analysis substantially. A sixth-order polynomial was therefore used to mathematically describe the mental maps.

The best-fit sixth-order polynomial surfaces for the mental maps of closeness to public transportation and closeness to bay beaches are shown in Figures 8 and 9. The basic features of the original mental maps are retained. The mental map for the bay beaches factor (Figure 8) shows the same inland distribution; the map for the public transportation factor (Figure 9) shows the predominant radial distribution with the influence of rail lines, especially for the Dandenong corridor to the Southeast. These maps exhibit much more regular contour variations and none of the isolated peaks and depressions shown in Figures 4 and 5.

PERCEIVED UTILITY SURFACE

To obtain the perceived utility surface of an area, it is necessary to multiply the matrix of mental maps obtained in the previous section by the matrix of importances as shown in Equation 5. The importance of each characteristic in the location choice decision is shown in Figure 10. As stated earlier, these ratings were obtained from the respondents in the study by means of semantic differential scales. The values shown in Figure 10 are average importances for all respondents and do not allow for individual differences.

To obtain a perceived utility surface on the same scale as the previous mental maps, Equation 5 was modified slightly to give

$$S = (I_k / \sum_{k=1}^{M} I_k) \times \{S_{ijk}\} \quad (7)$$

Thus, instead of obtaining a weighted sum of the satisfactions, one obtains a weighted average. Although this procedure contravenes theoretical evidence (12), it should make no difference in this situation since the sets of characteristics for all alternatives are the same size. It does have the advantage of making the mental

Figure 4. Mental map of satisfaction with closeness to public transportation.

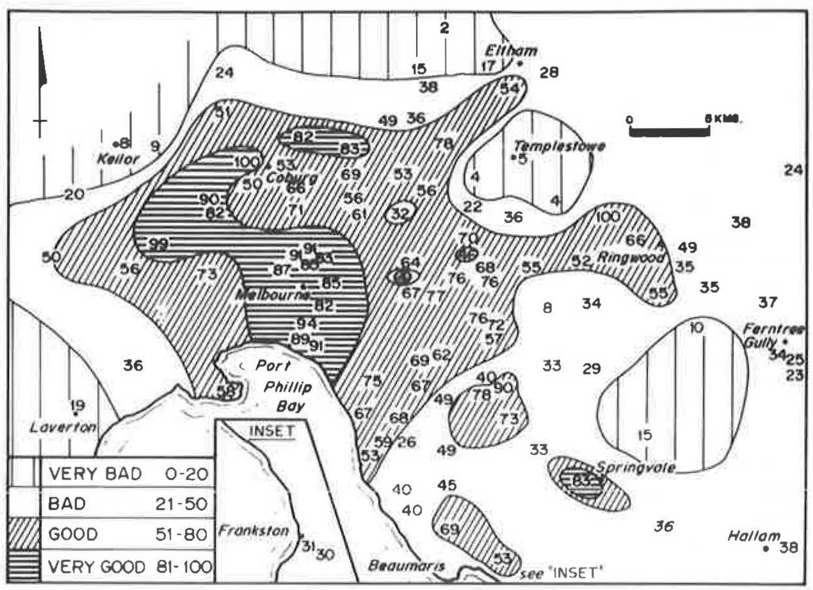
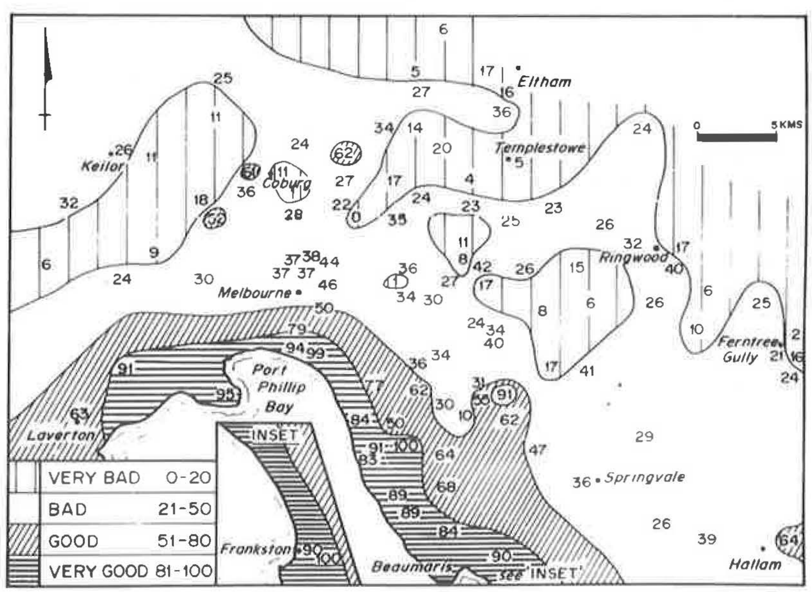


Figure 5. Mental map of satisfaction with closeness to bay beaches.



maps and utility surface easily comparable. The resultant utility surface is shown in Figure 11 (the utility values shown are on a 1:100 scale, where 1 represents completely unsatisfactory and 100 represents completely satisfactory).

The most desirable locations, according to respondents in the survey, are the inner suburbs and the Eltham area. This reflects the fact that many of the respondents were either students or young professional people who were probably aware of and in sympathy with the environmental advantages of a semirural area like Eltham but who for practical reasons lived close to work or the university in the inner-city area. The most undesirable areas were the northwestern suburbs and the vicinity around the industrial Springvale and Dandenong areas in the Southeast. Beyond Springvale, desirability improved as one reached areas like Frankston and Hallam.

AREA PREFERENCE SURFACE

Although Figure 11 gives a good indication of how the urban area of Melbourne is perceived by the type of person included in the survey, it does not indicate how such people would react to this perception in a choice situation. To convert the utility surface into an area preference (or choice) surface, one must apply Equation 6. The preference surface that results from using values of c = 0.1 is shown in Figure 12. The elements of this preference surface matrix represent the relative probabilities that a particular combination of latitude and longitude will be selected in a choice decision. Since the area of each location is constant, the elements also represent the potential residential density of survey respondents at that point.

The contour lines in Figure 12 show the percentage chance (or preference) of people locating in that area of Melbourne. Clearly, the most attractive areas are around the central city, Eltham and east of Hallam. The least attractive areas are in the Northwest and at Springvale and Dandenong.

To illustrate the effect of the sensitivity coefficient c, a new area preference surface was constructed by using c = 0.2. The resulting map is shown in Figure 13. As might be expected, when the sensitivity coefficient increases, the sensitivity of people to differences in the utility gained from living in each area increases. In terms of the actual preference surface, the peaks become higher and the troughs lower. The shape of the surface is more evident in the three-dimensional perspective drawing shown in Figure 14.

Obviously, the choice of the sensitivity coefficient

Figure 6. Change in correlation coefficient with increasing order of polynomial.

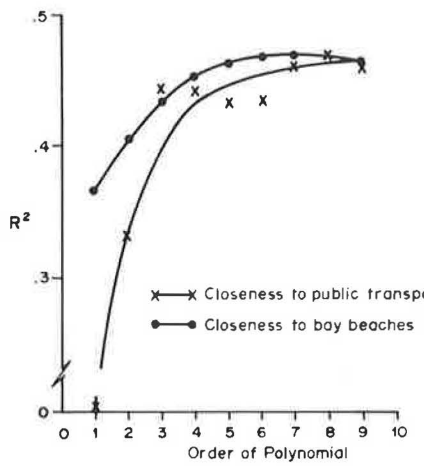


Figure 7. Change in F-ratio with increasing order of polynomial.

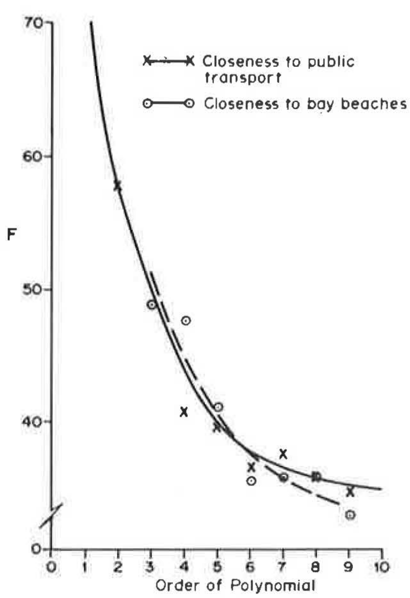


Figure 8. Polynomial surface mental map of satisfaction with closeness to bay beaches.

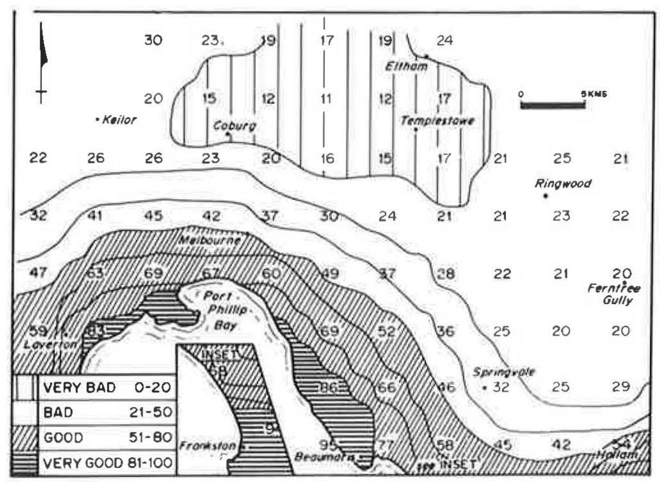
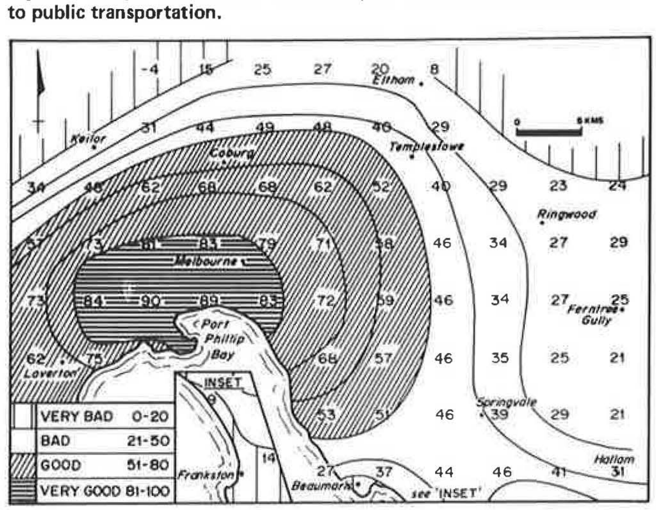


Figure 9. Polynomial surface mental map of satisfaction with closeness to public transportation.



has a great impact on the actual distribution of choice that results from a perceived utility surface. No attempt has been made in this paper to estimate this sensitivity coefficient. One possible technique would be to match the density distribution obtained from the model with an observed density distribution for the population in question (e.g., young married couples and professional couples with no children). Adjustment of the coefficient to achieve maximum agreement of the density distributions may result in a valid estimate of the sensitivity coefficient. Further research on this problem is needed.

USE OF THE MODEL

The model outlined in this paper has several uses:

1. The model can be used to estimate the area preferences of a particular group in a community. This group may be defined on the basis of socioeconomic classification or by current residential location. Such information would be most useful in migration studies such as those performed by Maher (13) and could also be collected on a regional basis to assist in the planning and prediction of the impact of the development of growth centers (14).
2. Since areas are described in terms of their characteristics, individual mental maps can be constructed to help isolate the perceptions and misperceptions of individual factors. Such information would be most useful in a marketing campaign to help promote particular locations.
3. Since each characteristic is considered individually, changes in each characteristic that may result from a change in the physical environment (e.g., an improved transportation system or a new regional center) can be traced through the model to assess their impact on the overall area preference surface.
4. Finally, and most important, since the output of the model is in visual form as a contour map (Figure 13), a perspective drawing (Figure 14), or a model of physical terrain, the uses of the model can be communicated to the decision maker with maximum effectiveness. No knowledge of the mathematics and equa-

Figure 10. Importance of factors in choice of residential location.

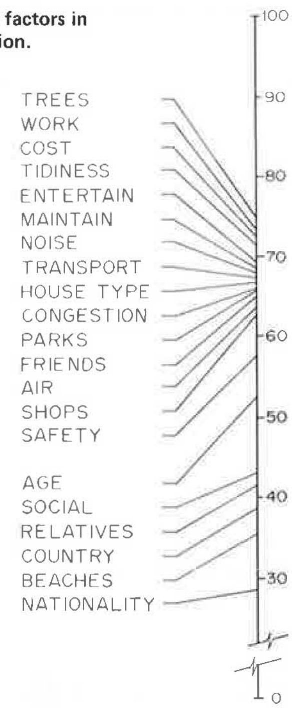


Figure 11. Perceived utility surface where U = ΣI x S/ΣI.

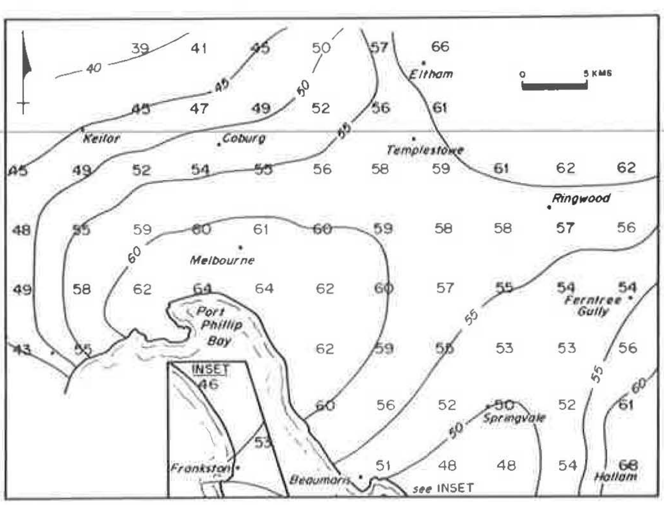


Figure 12. Area preference surface where c = 0.1.

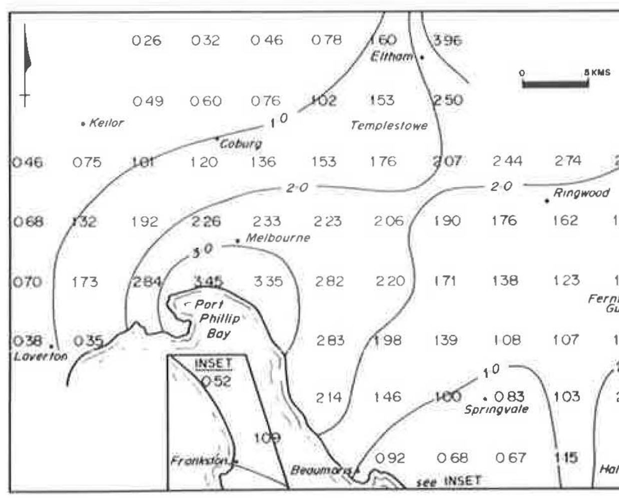


Figure 13. Area preference surface where c = 0.2.

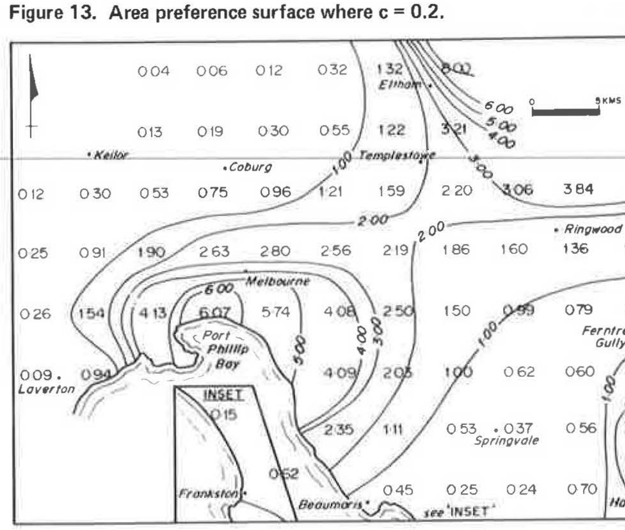
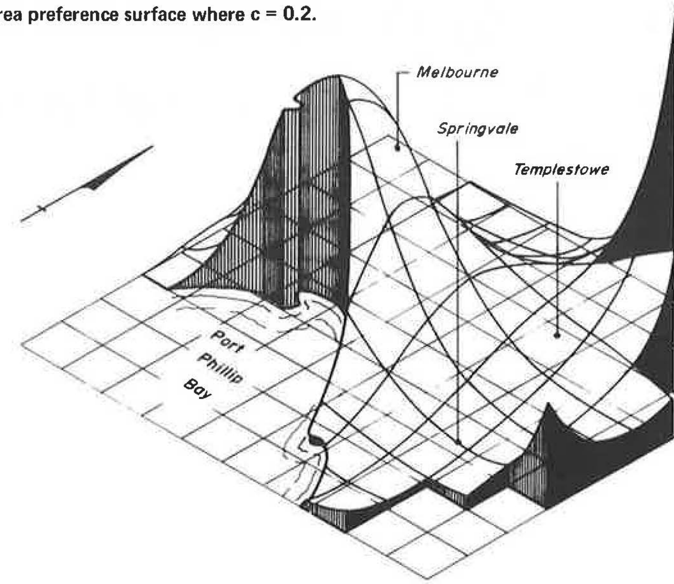


Figure 14. Three-dimensional view of area preference surface where c = 0.2.



tions is necessary for the decision maker to appreciate the effect of his or her policy decisions. In this regard, the model is ideally suited to use with an interactive computer graphics display.

CONCLUSION

By combining the feature of multidimensional mental maps with multinomial logit choice theory, the technique described in this paper makes it possible to present results in an easy-to-understand, visual manner. Such a technique should ensure maximum comprehension of the effect of transportation or land-use policies on the choice of residential location.

The model is demonstrated by using data collected from a survey of new residents of the inner suburbs of Melbourne. It is shown to produce in study respondents a logical and consistent perceptual view of Melbourne. Further research is needed on the choice of a sensitivity coefficient for use in the model.

The model is believed to be particularly useful in bridging the gap between the planner, the technologist, and the decision maker in the land-use and transportation planning task.

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Ethics of Politically Oriented Transportation Planning: Congruence and Conflict of Roles

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Some of the ethical implications of the involvement of transportation analysts in politically oriented planning processes, particularly in the context of urban transportation planning, are examined. The major point of departure is the concept of fragmentation of intellectual perspectives, which manifests itself among participants in the planning process, both professional and nonprofessional, and within the individual, who plays a variety of socially recognized roles. The pattern of congruences and conflicts created by the roles of professional transportation analyst, organization member, and participant in the political process is seen as the key to ethics for transportation analysts. Obligations imposed by each of these roles are identified and compared. The major conclusion is that these roles are, for the most part, congruent provided two key points are accepted: (a) that technical competence for transportation analysts consists of mastery of a variety of disciplinary perspectives and (b) that the professional's primary loyalty as a participant in the political process must be to the process itself and not to particular substantive outcomes.

Recent interest in the ethical aspects of transportation analysis seems to stem mainly from shifting perceptions of the nature of transportation decision making, particularly in urban transportation planning, and the role of transportation professionals in it. The increasing tendency to see transportation decisions as political rather than technical decisions and consequently to view transportation analysts as engaged in an explicitly political process has upset long-standing concepts concerning proper professional conduct and long-standing compromises among professional roles and the obligations imposed by them.

According to Marcuse (1), ethics "consist of a set of principles for the guidance of individual actions, extending beyond those established by positive law, and designed to promote the social good." Although some elements of this formulation are questioned in this paper, it can be adopted as a working definition of ethics. The purpose of the present discussion, then, is to derive principles to guide the actions of individual professionals in the "new" transportation decision-making process.

In seeking these principles, the first task is to describe how they operate in the lives of individuals. In so doing, we discover that there is an intimate relationship between our understanding of ethical issues and our fundamental ways of viewing the world. In the context of contemporary developments in transportation analysis, this relationship is of considerable importance: Our experience with transportation planning as a political process has not only upset our ideas of proper professional conduct but also posed a direct challenge to the understanding of social reality shared by most transportation professionals. This challenge, in turn, has implications for the way in which ethical principles are derived and applied.

The view of social reality that underlies practically all of the disciplines involved in transportation analysis is the utilitarian view, which holds (among other things) that there is something called the "public interest" or "social good"; that it may be defined as the sum total of individual utilities, properly weighted; and that, by making the proper trade-offs among conflicting values, an optimal balance among them can be achieved. This world view presupposes that the issues involved in social conflicts are sufficiently well defined, and conflicting perceptions of them sufficiently similar, to allow explicit trade-offs and compromises. Thus, the transportation analyst's world view tends to presuppose a social and political system in which everyone agrees on the structure of the issues although they may disagree about the desirability of particular outcomes.

The ethical position that most nearly corresponds to this view is situationism. Situationism denies the possibility of a set of absolutely valid ethical rules, holding rather that each ethical principle has relative value. In each situation, the individual must employ several rules but can arrive at the optimal action by achieving the proper balance among them. Although situationism fragments individual experience into more or less discrete situations, it views individual ethical values as forming a sufficiently integrated whole to allow trade-offs among them. Thus, the situationist's view of internal conflict and its resolution is directly parallel to the utilitarian's view of social conflict. Not surprisingly, much of the current discussion of the ethics of transportation analysis has been cast in situationist terms.

Both situationism and utilitarianism must meet two very important objections. The first of these is that neither ethical nor social issues are sufficiently unified to allow explicit trade-offs to be made among values. The alternative position, which has been advocated by authors such as Kuhn (2), Koestler (3), and Churchman (4) as a description of how we think about physical reality as well as social and psychological reality, is that human knowledge is organized into more or less internally consistent systems of belief and evidence (called, by various authors, paradigms, matrices, or frameworks) that may not display any great overlap in their fundamental premises, their structures, or their sense of the significance of particular facts and issues. If this is the case, no trade-offs, compromises, or even real debates are possible since the true problem is not that the various "sides" of a social issue (or an ethical question) are in conflict but that they are never able even to encounter one another in a meaningful sense.

In the context of the open transportation planning process, the challenge to this fragmented view of social and psychological reality is quite serious since several observers of politically oriented transportation planning processes have discovered a great deal of fragmentation in the way participants view the issues. Gakenheimer (5), for instance, writing of the Boston Transportation Planning Review, comments that

> Selective perceptions of the same problem can be so different as to be almost mutually exclusive in content. There are surprisingly few issues in which opposing perspectives are sufficiently congruent to constitute direct conflicts. Most topics are of interest to only one side in the argument and are disregarded by the other.

Other studies of politically oriented transportation planning processes—for instance, those by Jones and others (6) and Banks (7) on the planning activities of San Francisco's Metropolitan Transportation Commission—would tend to confirm this impression.

The second objection is that both utilitarianism and situationism seem to imply unlimited information and unlimited ability to make use of it. To arrive at the truly optimal solution for any system (or any ethical situation), one must know everything about it. In the case of situationism, a traditional objection has been that it demands faultless, instant analysis as well as complete information. Most people, it is objected, are simply not intelligent enough to apply situation ethics, and even if they were they would lack the time and resources. Again, these are not trivial objections for the transportation analyst engaged in an open decision-making process; important decisions must often be made in a crisis atmosphere in which information is scarce and fragmentary and there is little or no time for reflection.

Where does this leave us? If we never have enough time or information to make the optimal decision and if we often find that our experiences and values are so fragmented that we cannot even cast social and ethical questions in the form demanded by situationism and utilitarianism, is it even worthwhile to discuss ethics? More to the point, if we do discuss ethics, what should be the goal of the discussion?

If we see fragmentation and complexity as the chief intellectual barriers to the development of ethics, it follows that discussions of ethics should aim at the integration of fragmented perspectives, both in the individual and in society, and at the promotion of intellectual efficiency. One way both goals can be served is by a systematic comparison of perspectives to identify areas of conflict, congruence, and noninteraction. This is a first step in the process of integration of perspectives, which would ultimately involve the ability to state one perspective in terms natural to the other and to resolve any conflicts between them; it also serves the goal of intellectual efficiency since it allows areas of noninteraction and congruence to be eliminated from consideration.

Where conflict among our values does exist, we should look on ethical discussion and situational decision making as a learning process. Situationism views each situation as unique, but even situationists do not take this assertion so seriously as to suppose that there is no resemblance among ethical conflicts. If particular conflicts tend to recur, we eventually learn to recognize them and come to develop standard operating procedures for dealing with them. A second way in which ethical discussion can serve the goal of intellectual efficiency is by identifying recurring value conflicts and developing general strategies for dealing with them.

One way of describing the fragmentation of the individual personality is through the concept of socially recognized roles. Marcuse (1) identifies role conflict as the primary ethical issue for planners, and this analysis can easily be extended to other types of transportation professionals. According to Marcuse, planners play the following roles: professional planner, client-serving professional, professional acting in the public sphere, social scientist, guild member, public servant, citizen, and human being.

In the case of transportation professionals, this scheme needs to be modified to reflect the following special conditions in the transportation field:

1. Although there is a great deal of private-sector activity in transportation, most of what gets classified as transportation analysis is carried out by or for the public sector.
2. Most activity in the field is carried on by medium- to large-scale organizations.
3. The field is inherently multidisciplinary. Transportation analysts represent several different professions, and loyalties to specific professional societies and peer groups vary accordingly.
4. Current trends in the political organization of transportation decision making tend to thrust transportation professionals into roles as conflict managers and guardians of the integrity of the political process.

These considerations suggest that the key roles played by transportation professionals are those of (a) professional transportation analyst (which combines several of the roles identified by Marcuse), (b) organizational member, and (c) participant in the political process. The remainder of this paper sketches out the principal obligations implied by these roles and identifies the more obvious areas of role conflict and congruence created by them.

PROFESSIONAL TRANSPORTATION ANALYST

The role of professional transportation analyst includes not only functions analogous to Marcuse's "professional planner" but also the roles he identifies as "client-serving professional", "social scientist", and "guild member". Obligations imposed by these roles, as identified by Marcuse (1), include (a) respect for the opinion of other professionals, (b) technical competence, (c) independence of judgment, (d) allegiance to clients, (e) pursuit and publication of new knowledge related to professional matters, and (f) what Marcuse calls "guild obligations"—obligations imposed on their members by organized professions in an attempt to eliminate destructive competition.

The obligation of technical competence is central to the role of the transportation analyst as a professional. Obligations of respect for the opinion of other professionals and pursuit and publication of new knowledge are primarily supportive of the development and maintenance of technical competence in that technical competence is seen as being mastery of corporately defined knowledge, which is constantly evolving through the research activities of members of the profession. Independence of judgment and allegiance to clients, in turn, are intended to guarantee that the professional's technical competence will actually be brought to bear on particular assignments. Finally, guild obligations are intended (at least ostensibly) to provide an economic climate in which the development of technical competence and independence of judgment can flourish.

The primacy of the obligation of technical competence is obvious: The whole reason for involving professional transportation analysts in transportation decisions is that it is supposed that these decisions will be somehow better if they are informed by specialized knowledge. The individual professional's technical competence will depend on the degree of his or her mastery of some such knowledge and on the validity of the knowledge itself.

Professional knowledge bases consist of more or less coherent sets of facts, cause-and-effect relations, techniques of analysis for manipulating cause-and-effect relations, and values that say which cause-and-effect relations and facts are important. In an inherently multidisciplinary field such as transportation analysis, one finds a number of competing knowledge bases that differ in their fundamental sense of values as well as the facts and cause-and-effect relations they emphasize. Thus, fragmentation of perspective exists among transportation professionals as well as among nonprofessional participants in the transportation decision-making process.

This suggests that the most valuable sort of technical competence in a field such as transportation analysis may not depend so much on the individual's depth of mastery of any one disciplinary perspective as on that individual's ability to master a number of them—to view the same substantive problem from the point of view of an engineer, a planner, a geographer, an economist, a political scientist, an environmentalist, and so on. Thus, the technically competent transportation analyst is defined here as one whose knowledge is sufficiently broad to permit the analyst to integrate several different disciplinary perspectives yet sufficiently deep in each to protect him or her from misunderstanding and misapplying the principles of any one discipline. Needless to say, this type of competence is rare.

The obligations of independence of judgment and allegiance to clients imply that the professional must not only possess technical competence but must also be conscientious in applying it. Allegiance to clients (or employers) dictates that, as long as the client-professional relationship exists, the professional must serve the best interest of the client. Independence of judgment means that serving the best interest of the client implies that the professional must not be content to follow the whims or prejudices of the client as to either the definition of problems or the best means of solving them; because the professional is technically competent, it is the professional, not the client, who is uniquely qualified to understand problems and prescribe solutions, even if they happen to offend the client.

This understanding of independence of professional judgment makes it one of the more controversial professional obligations. It seems a bit arrogant to claim that professionals are uniquely qualified to understand problems and prescribe solutions, especially in light of what has happened to transportation decision making in the past decade. In a sense, the problem may stem from an inadequate understanding of what is meant by technical competence. Certainly, more than mastery of a narrow discipline in a fragmented field is required. Yet we cannot utterly abandon the obligation of professional independence without abandoning professionalism as well. If professionals' technical competence does not make them uniquely qualified to understand problems related to the professional knowledge base and prescribe solutions for them, of what value is it? Nevertheless, the obligation of professional independence can lead to important role conflicts.

Professional guild obligations operate primarily to regulate relations among consultants. Their intention is ostensibly to provide an economic climate in which technical competence and independence can flourish. Their actual effect, however, has long been controversial. Since it is not clear that professional guild obligations play an important part in the pattern of role conflicts and congruences in transportation analysis, they are not discussed further here.

ORGANIZATION MEMBER

Since almost all professional activity in transportation analysis takes place in the context of organizations, the role of the professional as an organization member and the obligations that it imposes are of critical importance. The primary obligations imposed by this role are loyalty to organizational mission and loyalty to organizational authority.

The concept of organizational mission implies that organizations, particularly public agencies, are created for a purpose. The obligation of loyalty to organizational mission implies that the individual, in joining the organization, subscribes to that purpose and agrees to give it wholehearted support.

Organizational missions are usually spelled out in charters, enabling acts, and the like and are subject to some sort of consensus that goes beyond the formalities of the charter and involves the organization, its immediate political environment, higher political authority, and the public. Nevertheless, such charters and informal understandings are never so definite that there is no room for interpretation or conflict over matters of detail. Moreover, organizational missions tend to change over time, sometimes drastically.

As a result, the obligation of loyalty to organizational mission is a frequent source of ethical tension for the professional. Alienation from organizational mission may result from either changes in the mission or changes in what the individual believes to be in the public interest. In some cases, the individual may come to believe that the organization's mission is actually contrary to the public interest and, in others, that it is basically good but inadequate to the needs of society. The obligation of loyalty to organizational mission implies that individual professionals should sever ties with any organization whose mission they cannot conscientiously support.

The concept of organizational authority implies that each organization will have an internal structure that consists of legitimate authority relationships. The obligation of loyalty to authority implies that, as long as authority remains legitimate, the professional is obliged to abide by the decisions of organizational superiors. Authority ceases to be legitimate when it is exercised contrary to the organization's commonly recognized mission, when it is exercised outside the commonly recognized organizational structure, or when it is exercised in violation of positive law or human rights as normally understood by the community.

PARTICIPANT IN THE POLITICAL PROCESS

Of the roles identified here as ethically significant for the transportation analyst, that of participant in the political process is probably the least understood. In the past, many transportation analysts would have denied that this was a valid professional role. Transportation decisions were viewed as technical decisions in which "community values", if they were considered at all, were just one more variable. Even today, many transportation analysts feel uncomfortable with overtly political planning processes, hoping that, even if the planning process itself cannot be apolitical, their role as professionals can raise them above the cut and thrust of partisan conflict.

Although the ideal of professional neutrality has carried over into much of the theoretical literature on the "open" planning process (8-13), several case studies of politically oriented planning processes (5-7) cast doubt on its practicality. Rather than seeking a role that will preserve professional innocence, we must seek one that will stress professional responsibility—in particular, one in which the transportation analyst can respect the integrity of the democratic process without wholly sacrificing the ideals of rationality and economy.

One way of looking at democratic systems is as a political response to fragmentation of perspective. It is a fundamental premise of democracy that no one viewpoint can ever be known to be uniquely valid and thus that political rationality is best served by direct expression of a full range of views on any public question. If fragmentation of perspective is not to lead to chaos or stagnation, a democratic system must permit action in the face of sharp and continued disagreement on substantive issues. Democracies commonly achieve this by insisting that the primary loyalty of individuals be given to the process rather than to particular substantive outcomes: As long as the rules of the process are followed, the individual is bound to accept the outcome as valid no matter how much he or she may disagree with it.

Although the rules will vary, depending on the situation, one fundamental rule will invariably be upheld: Political rationality, and hence the legitimacy of the process, depend on open discussion of the issues. Although fragmentation of perspectives usually precludes short-run consensus, discussion is the means by which the various perspectives on issues become known and by which they can sometimes be integrated. Without open discussion, democratic processes cease to be legitimate, and the condition on which the individual agrees to abide by the result is violated. This implies the first obligation of professionals as participants in the political process—that their primary loyalty must be to the political process itself, not to any substantive outcome, and this loyalty must include a commitment to open discussion of the issues.

Open discussion of the issues, however, does not imply unstructured discussion. It is essential to the success of democratic government that discussion lead to creative debate and that the participants' awareness of the issues and their interests in them be shaped, in part, by the political process itself. In cases in which perspectives on substantive issues are highly fragmented, the greatest danger to the democratic process is that discussion will degenerate into chaos. Such chaos can be as injurious to the legitimacy of the process as the deliberate suppression of viewpoints. In either case, the real problem is that some points of view have not been effectively heard and thus have not contributed to the decision. The professional's loyalty to the integrity of the political process must therefore include a commitment not only to open discussion but also to creative discussion.

The professional transportation analyst's commitment to open and creative discussion must avoid two extremes. The first of these is the attitude that only professional opinion is valid and that, since nonprofessionals do not really understand the issues, it is all right to patronize, mystify, or deceive them. It is never ethical for professionals—particularly those employed by public agencies, whose obligation to the integrity of the political process is legal as well as moral—to deliberately distort, misinterpret, or suppress information pertinent to a public decision. Such an action would normally imply that the professional's primary loyalty was to a substantive outcome, not to the integrity of the political process itself.

The second extreme is to deny all responsibility for the conduct and outcome of the process. In the past few years, debate on transportation issues has been marked by extreme fragmentation of perspective and has often threatened to degenerate into chaos. The involvement of professional transportation analysts in such debates, as professionals rather than as mere citizens, is altogether useless unless their expertise enables them to inject a sense of realism and order into the discussion.

In other words, too extreme an attitude of professional neutrality can be as injurious to the political process as can an attitude of technocratic arrogance. The difference between creative management of debate and uncreative manipulation of it is a subtle but crucial one. In the one case, the professional guides discussion into certain areas and away from others because this increases the productivity of the discussion; in the other, he or she does so to frustrate discussion and prejudice the outcome.

The professional transportation analyst's commitment to open and creative discussion can be expressed in several different ways, depending on the analyst's precise role in the political process. For employees of metropolitan planning organizations, this role will often involve some responsibility for managing the political process. Although the orthodox position among planning theorists seems to be that a strong, nonprofessional decision maker is essential to the open planning process, such an individual is rarely present in practice. Consequently, the responsibility for structuring decisions, developing and transmitting information, and managing debate often falls on staff members of planning agencies.

It is virtually impossible to be truly neutral in such a position. Professional staff members must make decisions about the scale of decisions, their sequence, and the development and dissemination of information about them. None of these activities is neutral; they all tend to stack the deck in favor of some outcomes and against others. Moreover, professional staff members are normally called on to make recommendations about substantive decisions despite suggestions in the literature on planning theory that this is not their proper role. In the real world, the governing bodies of planning agencies tend to demand staff recommendations either because it is politically expedient or because they lack the time to master the details of the choices before them.

In such a situation, the professional's commitment to open and creative discussion demands moderation and fairness on the one hand and commitment to efficiency of discussion on the other. The obligation of moderation implies a duty to try to keep conflict within manageable bounds. This involves, first of all, the development by the planning agency of enough political strength to defend the integrity of the process and, if necessary, the use of that strength. It also involves a conscientious effort on the part of the conflict manager to integrate perspectives where this is feasible. This, in turn, implies that transportation planners should take political analysis as seriously as they do any other kind of technical analysis and should seek to discover patterns of conflict and congruence in the perspectives they encounter.

The obligation of fairness involves maintaining an attitude of goodwill toward all participants in the planning process even though it may often be necessary to disagree with them on particular points. When professionals do take sides, they should be honest about their reasons for doing so and should be prepared to demonstrate that they have indeed taken all points of view into account.

The commitment of professionals to efficiency of discussion implies (a) that they should seek to guide discussion away from radically unsound alternatives so that valuable time and effort will not be wasted in developing detailed information about them and (b) that technical analyses should be designed to answer pertinent questions raised in the debate, not merely to develop information for information's sake. Technical competence, understood as the mastery of a variety of disciplinary perspectives, should make the professional uniquely qualified to judge the potential pertinence of particular bits of information. Within the bounds imposed by moderation and fairness, this sense of pertinence should guide the development of technical analyses in the open planning process.

For employees of implementing agencies, participation in the planning process may well involve advocacy of particular transportation facilities or services. Although the professional in an advocacy role has an obligation to make a strong case for his or her point of view, loyalty to the integrity of the political process suggests that moderation and fairness are still essential. Advocacy must be limited by an awareness that its true purpose is to contribute to the rationality of the political process, not to detract from it. This means, among other things, that professionals have an obligation to make their case an honest one: They are never justified in concealing their true motives or in deliberately distorting, misinterpreting, or suppressing pertinent information.

Consultants may fill a number of different roles in politically oriented planning processes. Presumably, consultants could be employed as advocates of particular positions, as developers of narrowly defined technical information, as communications specialists in the participatory process, or even as managers of the political process (the Boston Transportation Planning Review was managed by a consortium of consulting firms). If conducted openly, any of these roles could be legitimate ones in the open planning process. Consultants share their clients' obligations to promote open and creative discussion of the issues. Ideally, where consultants are employed by public agencies involved in politically oriented planning processes, there should be some sort of understanding between the consultant and the agency that spells out the consultant's responsibility in the political process.

CONGRUENCE AND CONFLICT OF ROLES

In examining the pattern of role congruence and conflict, we are primarily concerned with the question of whether a stable ethical position is possible for transportation professionals engaged in a politically oriented planning process. It would appear that such a stable position is possible—that is, that the roles we have examined are for the most part congruent—provided two key points are accepted: (a) that technical competence for transportation analysts consists of mastery of a variety of disciplinary perspectives and (b) that the professional's primary loyalty as a participant in the political process must be to the integrity of the process itself.

A strong congruence exists among the obligations of technical competence, loyalty to the organizational mission, and commitment to efficiency in political discussion. The obligation of professionals to wholeheartedly support the mission of their organizations implies an obligation to show concern for the organization's effectiveness. This, in turn, implies not only an obligation to exert reasonable effort in the organization's behalf but also an obligation to acquire and develop skills that are useful to the organization in carrying out its mission. Since the skills that make transportation analysts technically competent would normally be of utmost importance to the mission of their organizations, professionals are serving both professional and organizational obligations by increasing their technical competence.

Technical competence is also congruent with efficiency in political discussion as long as technical competence is understood to be the mastery of a variety of disciplinary perspectives. We have suggested that the goal of efficiency in discussion is one of limiting the expensive development of information to items that are realistic and truly pertinent to the debate. If the professional has really mastered a full range of disciplinary perspectives, this technical competence should be a reliable guide to what is realistic and pertinent.

Interactions among the obligations imposed by organizational membership and participation in the political process can produce either congruence or conflict, but they should be mostly congruent if organizational missions are properly understood. A strong congruence exists between organizational loyalties and loyalty to the integrity of the political process; weak organizations (especially weak planning agencies) do not make for effective, open political processes. Internal order and efficiency are important to planning agencies not only in maintaining the political strength needed to defend the integrity of the planning process but also in reducing the tendency to chaos created by time pressures and fragmentation of perspective.

Conflict between loyalties to organizational mission and authority and the obligations of moderation and fairness in the political process usually results from the organization's failure to subordinate substantive outcomes to the integrity of the political process in determining its mission. In many cases, violation of the obligations of moderation and fairness will be prima facie evidence of illegitimacy in organizational missions, particularly where honesty and fairness in handling information are at issue.

This obligation to be open and honest in handling information extends to consultants who are retained by public agencies. Although acceptance of a contract obligates consultants to some degree of loyalty to their clients' missions, it does not absolve them of all concern for the legitimacy of those missions. It is a perversion of the client-consultant relationship for a public agency to employ a consultant not to tell the agency what it cannot otherwise find out but rather to tell the public what the agency wants it to hear; consultants have an obligation to discourage agencies from retaining them for such purposes. Although the possibility of such arrangements constitutes a real temptation for consulting firms, it produces no ethical conflict except in the case of individuals who suspect their organizations of engaging in illegitimate activities.

The major source of role conflict for transportation analysts is the obligation of independence of judgment. Not only does this obligation sharpen the potential conflict between individual conscience and organizational loyalties (which would exist for a nonprofessional as well), but, if improperly understood, it can also create a conflict with the obligations of moderation and fairness in the political process.

Although their obligations as human beings and as citizens play a part in the potential alienation of professionals from organizational mission, their understanding of the good of society will be shaped primarily by their professional values and the opinions of their professional peers. Thus, their obligation to support their organization's mission will most often be challenged by their perception, as professionals, that the organization's mission is illegitimate or inadequate.

Professional values and opinions may also lead the individual to believe that proposed organizational actions, although legitimate, are ill-advised. When this happens, the obligations of independence of professional judgment and loyalty to organizational mission may conflict with loyalty to organizational authority. In this case, what is at stake is organizational effectiveness. The two cases are fundamentally different: Where organizational actions are perceived as illegitimate, the professional may have an obligation to carry the dispute outside the organization; where they are merely ill-advised, disagreement should normally be confined to the organization itself.

Conflicts between professionals' independence of judgment and their loyalty to the political process will occur if they place more value on particular substantive outcomes (suggested by their professional judgment) than on the integrity of the political process. This type of conflict is less likely to occur if professionals recognize that their obligation to independent judgment depends on the reality of their technical competence and that their technical competence depends on more than mastery of a narrow disciplinary perspective.

CONCLUSIONS

The purpose of this paper has been to analyze the pattern of congruences and conflicts created by the interaction of the transportation professional's roles as professional transportation analyst, organization member, and participant in the political process—the last role being understood as one that is created by participation in open or participatory planning processes, particularly in the context of urban transportation planning. The major conclusion of this analysis is that a fairly stable ethical position should be possible for transportation analysts engaged in open planning processes. Achievement of this position depends primarily on redefining technical competence to mean mastery of a variety of disciplinary perspectives and on an understanding among professionals that their primary loyalty should be to the integrity of the political process rather than to particular substantive outcomes.

Significant obligations imposed by the transportation analyst's role as a professional include technical competence and independence of judgment, those imposed by the role of organizational member include loyalty to the organizational mission and loyalty to organizational authority, and those imposed by the role of participant in the political process include loyalty to the integrity of the political process and commitment to efficiency in discussion.

Congruences exist among the obligations of technical competence, loyalty to the organizational mission, and commitment to efficiency in discussion. Congruences also exist between loyalty to the integrity of the political process and loyalty to organizational mission and authority provided organizational missions subordinate substantive outcomes to the integrity of the political process.

The obligation of professionals to exercise independent judgment may conflict with their obligations of loyalty to organizational mission and authority, particularly where organizational missions are perceived as illegitimate or proposed organizational actions are seen as ill-advised. Independence of judgment would normally not conflict with the obligation of loyalty to the integrity of the political process as long as the individual properly understands the obligations of technical competence and loyalty to the political process.

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