6. Highway Jurisdiction. Program Management Division, Federal Highway Administration, July 1978.
7. Statewide Highway Planning: Digest of Planning Activities—Regions 4, 6, and 7; Regions 1 (North), 5, 8, and 10. Program Management Division, Federal Highway Administration, June 1978 and February 1978.
8. National Functional System: Mileage and Travel Summary; 1976 National Highway Inventory and Performance Study. Office of Highway Planning, Federal Highway Administration, June 1977.

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Subarea Diagnostic and Evaluative Procedures for Programming Short-Range Transportation Improvements

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The emphasis on low-cost, short-range transportation system management actions implies the need for more detailed data to support decision making at a smaller scale. Ideally, such data would be developed efficiently and in a manner conducive to identification of problems and opportunities and, ultimately, formulation and programming of improvements. At the same time, such data must permit planners to perform the necessary trade-offs of traditional mobility objectives against the increasingly important objectives of improved air quality, reduced energy consumption, and responsible fiscal management. This paper describes the development and case-study application of a diagnostic framework for subarea-level identification of problems and delineation of improvements. The necessary level of detail is provided by use of the thoroughfare planning system, a subarea focusing methodology. A framework is set forth for using such a tool to develop diagnostic measures pertaining to environmental as well as mobility objectives. The diagnostic measures obtained in a case-study application are described. Further, the use of these measures to formulate an improvements program within the case-study setting is reviewed, with particular attention to the packaging of individual candidate projects into distinct alternatives for evaluation and selection.

An essential responsibility of a metropolitan planning organization is to assist local governments in making transportation investment decisions. In the past, however, it has been difficult to provide adequate information to support local decisions. Regionwide analysis and evaluations of major highway and transit facilities simply are not detailed enough to address problems at a subregional scale. Much thought has been given to the development of planning methodologies that are geared to cost-effective analysis of subregional problems, and several recent developments appear promising (1, 2, 3). One such methodology is the thoroughfare planning system (TPS), developed by the North Central Texas Council of Governments in close cooperation with member governments. The TPS features a rich, hierarchically structured data base and an automatic subarea focusing capability. It provides low-cost analyses of transportation systems in substantially greater detail than was previously possible. The mechanics of TPS are adequately described elsewhere (4, 5). The subject of this paper is the application of subregional analysis in decision-making contexts of increasing complexity.

Recent legislation and other considerations have created a situation in which the objectives of transportation planning, at all levels, are more complex and are often in conflict. Short-term, low-capital transportation system management (TSM) actions must be explored before resorting to capital-intensive alternatives. The implementation of TSM actions must consider the progress of long-range developments. Fiscal constraints and environmental concerns temper the traditional objective of increased mobility. These manifold objectives require a well-structured diagnostic and evaluative process to guide the identification of effective improvements to the transportation system.

This paper describes a framework for systematic and comprehensive review of a local transportation system. It focuses initially on travel patterns (rather than on specific facilities) in order to formulate a more cohesive and effective set of system enhancements, including systemwide actions as well as facility-specific improvements. A by-product of this approach is the ability to address questions of equity more readily—questions such as whether trips to and from a particular residential zone are adequately served in terms of mobility, energy efficiency, and other objectives.

TPS

TPS is designed to answer many of the needs that arise from a shift in planning emphasis—from large-scale, capital-intensive projects to low-cost subregional projects, typified by TSM strategies. The ability to analyze small-scale problems quickly and inexpensively is essential. In the formulation of a local capital improvements program, for example, information is needed on an adequate range of options within the time constraints imposed by the decision-making process. The principal elements of the TPS include the following:

1. An approved regional thoroughfare plan, complete with design standards;

2. A base inventory of the thoroughfare system with procedures for continuous updates;
3. A thoroughfare information system, which facilitates the storage and easy access of both inventory data and analysis results; and
4. A thoroughfare analysis process to evaluate the impact of alternative strategies.

To provide for cost-effective analysis of small-scale problems, the TPS features several innovations:

1. Computerized procedures build subfiles for analysis from base data files that describe the zones and networks of the region in much detail. Typically, these subfiles include detailed presentation for the area of interest, with detail decreasing gradually with distance from the area of interest.
2. The subarea focusing feature is supported by a rich, hierarchically structured data base. At the finest level of detail, approximately 5000 zones and 12 000 links are represented for a study region covering 6600 km^2 (2550 miles^2). Per-user specification for a particular problem, automatic aggregation of zones, and deletion of links in focusing may result in 100 to 300 zones and 1000 to 3000 links for analysis.
3. To facilitate the evaluation of alternatives, the outputs of the analysis process are input to a special module for an automatic accounting of major impacts. Several categories of impact measures are reported in concise format: system supply and mobility measures, socioeconomic data, energy consumption, and emissions calculations.

DIAGNOSTIC FRAMEWORK FOR SUBAREA IMPROVEMENTS PROGRAMMING

Listed below are impacts of interest and the associated measures used in the analysis.

Condition	Measures
Accessibility	Average length of trip from subarea Percent of subarea trip origins destined outside subarea
Mobility	Vehicle kilometers of travel on subarea links Speed in subarea (posted, free, final) Delay in subarea (due to traffic controls, due to congestion)
Route directness	Route distance ÷ airline distance
Propensity for diversion	Time via minimum-distance path ÷ time via minimum-time path
Energy	Fuel consumption
Air quality	Emissions

Although most of these are standard evaluation measures, some may bear further discussion.

The signal delay due to traffic controls is defined as the difference between average posted speed limit and average free-flow (zero-volume) speed. This measure is particularly useful for the formulation of TSM strategies to improve traffic circulation. Signal delay is often several times greater than congestion delay and is often less costly to reduce.

Route directness is calculated as the ratio of route distance to airline distance. This measure may indicate either sparseness of the transportation network or diversion to longer paths. The former may point to capital projects to improve network support of particular zones. The latter may point out possibilities for reduction of vehicle kilometers of travel through improved arterial circulation.

The propensity for diversion to longer paths is measured by a travel-time ratio, the time on the minimum-distance path divided by the time on the minimum-time path. Values greater than one indicate a propensity for diversion to longer but faster paths. Analysis using this ratio can point to opportunities for reduction of the vehicle kilometers of travel.

Calculation of Measures in Subregional Analysis

To isolate problems within a subarea of interest and to ensure that effects within the subarea are not drowned out by regionwide effects, the calculation of performance measures should pertain to the subarea network only. One would, for example, be concerned with average speed within the subarea, calculated as the ratio of subarea vehicle kilometers of travel to travel time. For such analysis, it is necessary to build special skim trees whose path impedances are summed only over links within the given subarea. Figure 1 illustrates the calculation of subarea travel time for a specific path.

When the scope is restricted to subarea effects, care must be taken to avoid suboptimization, i.e., improvement of a local system in a manner detrimental to adjoining localities or to the region as a whole. Closely related is the need to order by priority the improvement programs of different communities to ensure that funds are channeled toward the most urgent problems. Thus, a diagnostic framework is needed for evaluation of subareawide performance (for comparison to other subareas within a study region), as well as for detailed analysis of problems within the subarea.

Diagnostic Framework

1. Subareawide evaluation reviews the overall performance of the local transportation system. This evaluation can be used in setting the priorities of subareas or corridors and may also be directly applicable in identification of generalized TSM actions or control strategies (e.g., a communitywide carpool promotion program).
2. Detailed diagnostic analysis examines the local system in detail to identify specific problems and opportunities for improvement with respect to mobility, energy consumption, and air quality. A systematic procedure is set forth below, beginning with the trip patterns served by the subarea transportation system and working toward identification of specific problems and candidate improvements. A schematic of this procedure is shown in Figure 2.

Identification of problem zones comprises the calculation of zone-related performance measures, based on trips to and from each zone in the subarea. Zones that produce or attract a significant number of trips that are inadequately served with respect to such factors as mobility or energy efficiency are singled out for further analysis. An important by-product is that questions concerning equity in the service to different sectors can be frontally addressed by zone-related performance measures.

For each of the problem zones, problem pairs of zones are identified. These are the specific trip interchanges that most need improved service. The paths associated with problem interchanges are then examined and specific facilities are examined in relation to problem zones and zone pairs.

Facilities on and near problem paths are examined for opportunities to reduce signal delay, divert traffic from congested highway links, and provide more direct routing. Finally, possible improvements are specified, taking into account the availability of funds, the priority of various needs, and detailed identification of problems and opportunities.

CASE STUDY: ANALYSIS OF BASE CONDITIONS

To demonstrate the application of the diagnostic framework, a case-study analysis of 1980 conditions was performed within the subarea depicted in Figure 3, which is located between Dallas and Fort Worth. The performance of the highway network in the subarea was evaluated; the objective was to formulate a hypothetical improvement program. The subarea network is bounded on the north and south by freeways running east-west, and contains a partially complete freeway, which runs north-south. The focus of the analysis was the arterial system—its support of the freeways and the quality of service to local traffic.

To better analyze congestion effects, separate traffic assignments were run for morning peak, evening peak, and off-peak travel. The assignment results were then assessed by following the diagnostic framework previously set forth.

Figure 1. Calculation of subarea travel time.

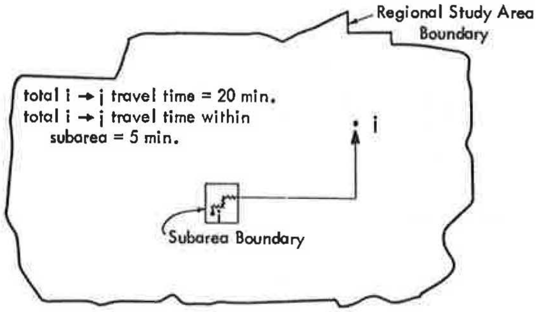


Figure 2. Detailed diagnostic analysis work flow.

Subareawide Diagnostics

Subareawide impact measures were calculated for the following classifications:

1. Roadway functional classification;
2. Trip purpose [home-based work (HBW), home-based nonwork (HNW), non-home-based (NHB), other];
3. Time of day (morning, evening, off-peak); and
4. Trip orientation [starting and ending within the subarea (I/I) starting within and ending ouside the subarea (I/E), starting outside and ending within the subarea (E/I), through traffic (E/E)].

As an example, the analysis of delay components is shown in Figure 4. On nonfreeway links, signal delay is several times greater than congestion delay. By trip purpose, HBW, HNW, and NHB trips experience less signal delay than do other trips (mainly truck and taxi trips). The time-of-day results show greater delay in the evening peak than in the morning peak. The E/E traffic experiences greater delay than do other trip orientations.

No attempt is made here to fully explore the subareawide results. It is difficult to draw conclusions from such results because little literature on subarea analyses is available for comparison and different subareas have different characteristics. Nonetheless, subareawide performance measures would clearly be useful for setting the priorities of investments within a study region and could also be used to identify subareawide TSM actions. For example, morning peak congestion delay in Figure 4 could perhaps be addressed by programs that promote staggered work hours or flextime. Since the evening peak period is already rela-

Figure 3. Case study: subarea boundary.

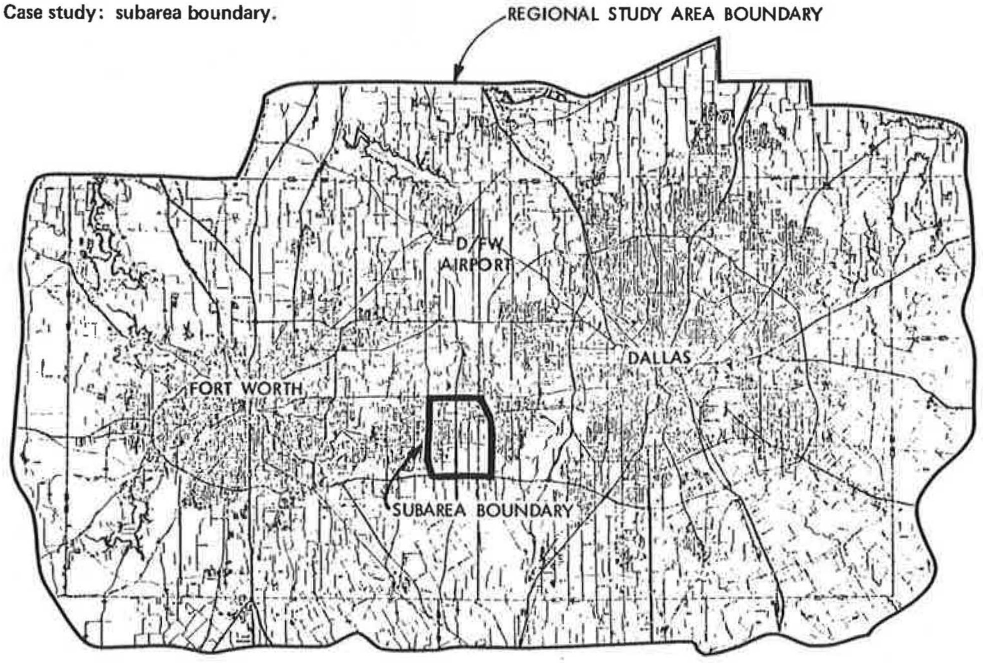


Figure 4. Case-study base condition diagnostics: delay components (percentage total free-flow travel time).

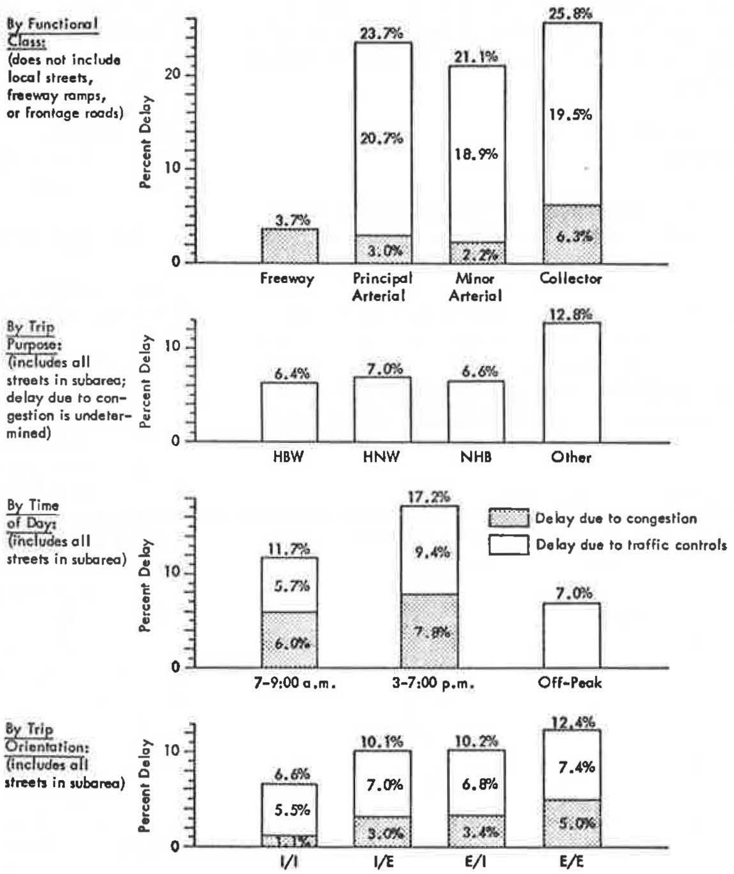
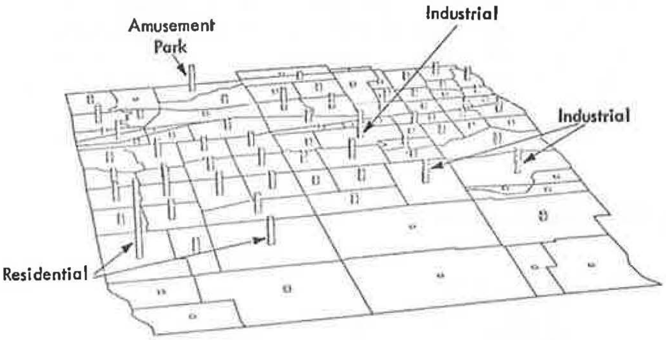


Figure 5. Subarea zones with signal delay.



tively broad and flat, however, promotion of a four-day work week might be more effective. The analysis of vehicle kilometers of travel by trip purpose, as another example, could point to opportunities for reduced vehicle kilometers of travel, emissions, and energy consumption through promotion of carpooling for work or nonwork travel.

Zone-Based Diagnostics

The detailed diagnostic analysis is trip based rather than link based, focusing initially on the trips served by the network rather than on specific facilities. The first step of the trip-based analysis (as illustrated in Figure 2) is the calculation of zone-related performance measures, which pertains to trips to and from each zone (rather than the links within each zone). Zones with subpar performance are then marked for further analysis. To illustrate, subarea zones that experience excessive signal delay are indicated in Figure 5. The zones in-

Figure 6. Subarea network: facilities contributing to signal delay.

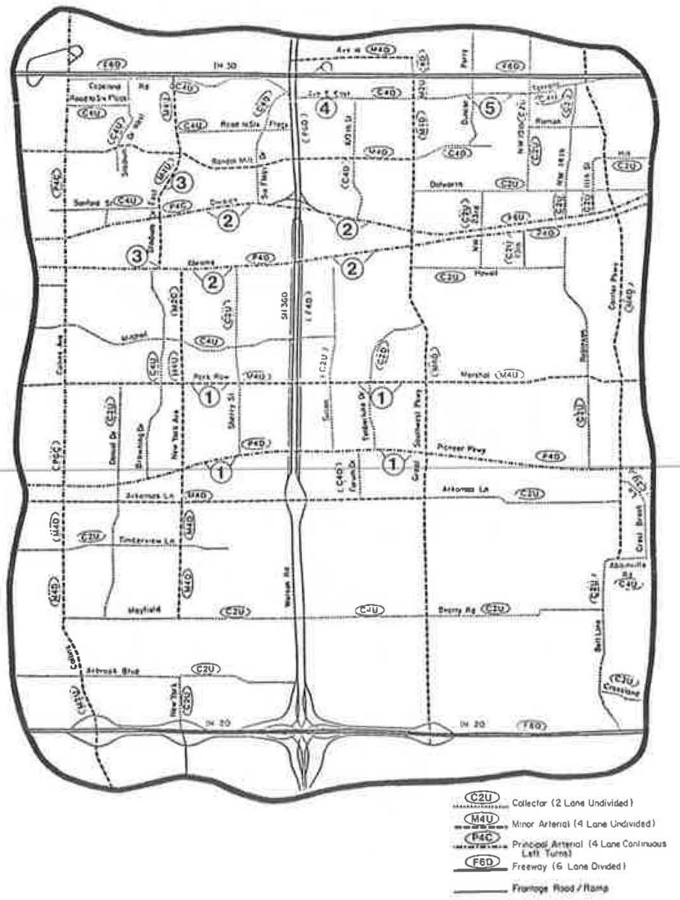


Table 1. Objectives and problem statements.

Objective	Statement of Problem
1. Improve north-south travel in western portion of subarea	North-south travel is circuitous; congestion delay makes up 16-25 percent of total travel time, a rate 8-12 times the subarea mean; traffic control delay makes up 15-20 percent of total travel time, a rate 3-5 times the subarea mean.
2. Improve east-west travel in northwestern portion of subarea	East-west travel experiences traffic control delay 14-20 percent of total travel time, a rate 2½ to 3½ times the subarea mean.
3. Improve east-west travel in southwestern portion of subarea	East-west travel experiences congestion delay 13-21 percent of total travel time, a rate 6-10 times the subarea mean; traffic control delay up to 20 percent of total travel time occurs at a rate 3½ times the subarea mean.
4. Improve transition from east-west travel to north-south travel in northeastern portion of subarea	Travel routes experience congestion delay between 20-40 percent of total travel time at a rate 10-20 times the mean for the subarea.

Table 2. Summary of improvement packages.

Objective	Package	Description	Cost Estimate ($)
1. Improve north-south travel in western portion of subarea	1-A	Provide a continuous north-south arterial route	2 200 000
	1-B	Provide freeway interchange and more direct arterial access	2 425 000
	1-C	Enhance traffic signal coordination and expand arterial capacity	1 101 000
	1-D	Construct additional freeway lanes and interchange	11 000 000
2. Improve east-west travel in northwestern portion of subarea	2-A	Provide new freeway interchange and coordinate arterial traffic signals	10 225 000
	2-B	Expand arterial capacity and eliminate an intersection	4 275 000
3. Improve east-west travel in southwestern portion of subarea	3-A	Enhance design of an underutilized arterial roadway	1 800 000
	3-B	Expand capacity along an existing arterial	3 600 000
	3-C	Restrict access to and from an existing arterial	550 000
	3-D	Construct grade-separated intersections along an arterial	6 550 000
4. Improve transition from east-west travel to north-south travel in northeastern portion of subarea	4-A	Provide freeway interchange and expand arterial capacity	4 610 000
	4-B	Provide a limited access interchange	2 000 000
	4-C	Construct a continuous arterial route and eliminate controls	3 650 000

dicated are those for which (a) the ratio of delay to travel time exceeded the subarea average by one standard deviation and (b) the delay for the zone constituted a significant portion of the total delay in the subarea.

For zones thus indicated, the next step is to determine the zone pairs that cause the problem. Standard urban transportation planning system (UTPS) software is used to calculate the impact measure in question for each trip interchange from these zones. Troublesome interchanges are then marked for the next step, which is to plot and inspect the paths traversed by traffic on these interchanges. From these plots it is then possible to relate problems to specific facilities or groups of facilities. Figure 6 is a map that identifies facilities contributing to signal delay. The circled numbers in Figure 6 correspond to the following problems:

1. Poor east-west mobility because of signal delay on arterials spanning the southern part of the subarea (since one of the facilities indicated already has a progressive signal system, the solution may lie in reducing the number of signals by limiting access),
2. Poor east-west mobility in the northern part of the subarea suggests the need for progressive signalling or limitation of access,
3. Poor north-south mobility in the northwest quadrant hinders access to the heavily residential zones in the southwest quadrant (simple realignment would eliminate one intersection and reduce signal delay),
4. Excessive signal delay at the freeway interchange to the north, and
5. Excessive signal delay getting onto the freeway in the northeast quadrant impedes access to industrial zones (more direct access to the freeway is needed).

Congestion delay, route circuity, and posted speed were also analyzed. Route circuity is indicative of excessive vehicle kilometers of travel and can point to opportunities for reduced emissions and energy consumption. Posted speed can be thought of as an upper limit on the accessibility to different sectors and, along with components of delay, determines operating speed.

Other auxiliary analyses of the network are useful in moving from diagnostic analysis to specification of improvements. Maps of currently underutilized links can be used to delineate alternative routes for diversion from congested facilities. Links where parking is currently allowed also have a potential for increased capacity.

FORMULATION OF TRANSPORTATION IMPROVEMENTS

The first step toward identification of specific improvements in the subarea was to use the diagnostic results to delineate a manageable number of distinct problems that should be addressed. Use of diagnostics in this manner often carries built-in justification for projects. Solutions to seemingly distinct problems often have interdependent effects; later, in the packaging of different combinations of improvements, an attempt was made to account for possible interrelationships.

Four generalized problem areas were identified for the subarea in question. For each area, an overall objective and a specific problem statement are provided in Table 1. Problems cited include circuity of travel, congestion delay, and traffic control delay. Although mobility objectives are a major thrust, programming goals are not restricted to mobility improvements only. The elimination of congestion and traffic control delay will often also reduce emissions and energy consumption, as a result of decreased travel time over a more uniform travel speed profile. In addition, the elimination of circuitous travel can reduce vehicle kilometers of travel for certain trips, further reducing energy consumption and emissions.

Initial Project Definition

Four types of projects were considered: new construction, existing road expansion, restriction of access, and traffic control improvements. Construction projects included interchanges as well as road segments. Projects to restrict access included turning-movement prohibitions and restrictions of midblock land access. The traffic control improvements included signal coordina-

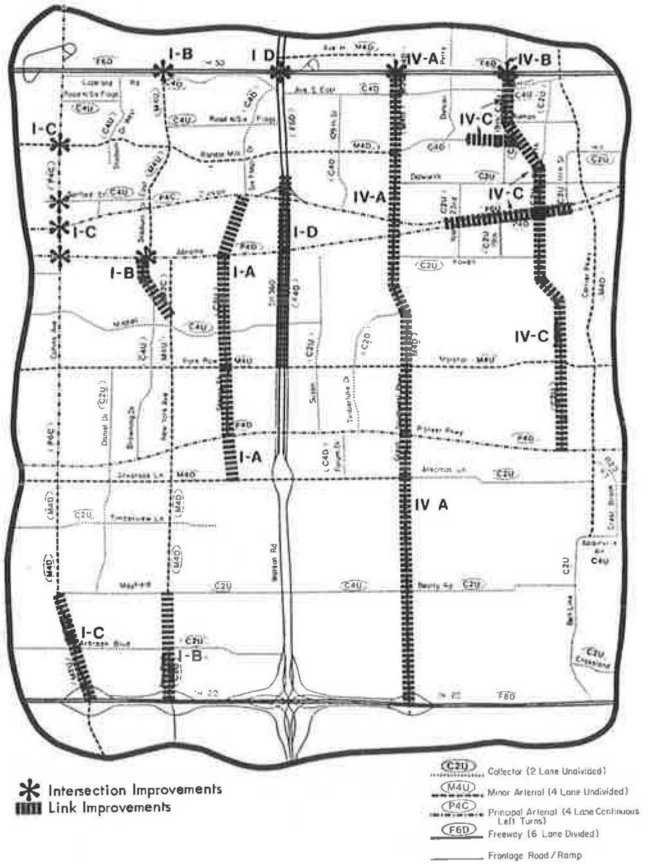


Figure 7. Project packages: objectives 1 and 4.

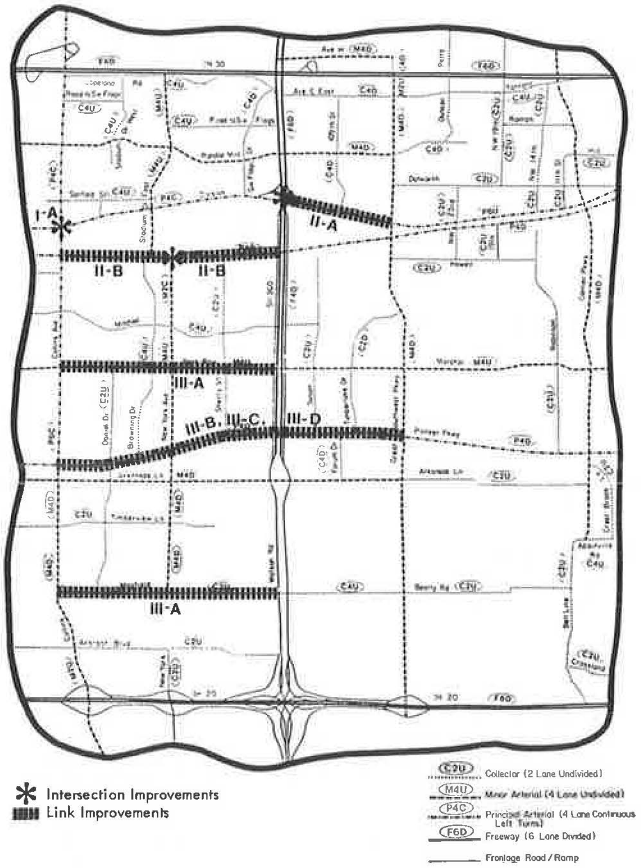


Figure 8. Project packages: objectives 2 and 3.

tion, traffic control removal, and traffic control modification. For the subarea in question, a total of 34 individual projects were initially considered. These projects were then combined into project packages before further consideration.

Individual projects are not always sufficient to produce desired increments in the objectives being measured. When grouped, projects can either reinforce one another or produce counterproductive results (6, 7). The next step, therefore, was to package individual projects together to form a manageable number of alternative solutions for each of the four problem areas in Table 1. In all, 13 separate packages were assembled from the list of possible projects proposed for the subarea. A summary of each package and its cost is provided in Table 2. The packages for objectives 1 and 4 are illustrated in Figure 7. Figure 8 shows the packages for objectives 2 and 3. The cost of the various packages ranges from $0.5 million to $11 million.

Selection of Improvements for Further Consideration

The initial identification and packaging of projects were based on the quantitative diagnostic analysis described previously. Final selection took into account additional qualitative arguments: political acceptance, economic feasibility, safety, and additional costs such as right-of-way and relocation.

A total of nine projects was selected, at an estimated cost of $9 925 000. For objective 1, package 1-A was selected. It is anticipated that this set of improvements will provide a much-needed continuous north-south arterial by means of improvements to an existing roadway in a non-politically sensitive area by using a variety of available funding sources. For objective 2, package 2-B was selected to improve east-west access to regional employment centers along the route because of available right-of-way and ease of construction. For objective 3, only a part of package 3-A was selected, to reduce cost and avoid duplication of benefits from package 1-A and to improve the access to a fast-growing sector of the subarea. For objective 4, a portion of package 4-A (the new freeway interchange) was selected to alleviate volumes at adjacent interchanges and to provide better access to industrial zones in the southeast sector.

The final selection of packages recognized that funding for individual projects could come from a variety of different sources, including federal aid, state aid, and local funding. Once a final selection is made, the remaining packages are tested as a group in order to see whether the results are valid and logical. The validity of projects can be tested in this manner, and thus a large portion of the guesswork is removed from the transportation programming process.

FUTURE WORK

This paper sets forth a diagnostic procedure for identification of problems and opportunities and delineation of candidate improvements. The features of this process are (a) orientation of the diagnostic measures to trip patterns rather than facility-specific measures, using zone-related performance measures as a starting point; and (b) assessment of performance in sufficient detail and breadth to support small-scale, short-range decision making in the face of multiple objectives. It would be difficult to prove that such analysis always leads to more effective improvements; however, in case-study application the analysis provided a comprehensive overview of the pattern by which specific facilities contribute to problems, guided the specification of improvements, and lent itself readily to the justification of proposed improvements in terms of trip interchanges and activity clusters being served. Areas requiring further work include the following:

1. The evolution, from future subarea studies, of suitable benchmarks against which to compare the subareawide diagnostics, so that these measures may be used to set priority subareas for funding and to specify subareawide strategies;
2. Development of more rigorous guidelines for what constitutes a problem zone or zone pair—the heuristic rules used in this paper call for further examination; and
3. Development of more rigorous guidelines for formulation of distinct objectives and packaging of individual projects into alternatives for addressing these objectives.

ACKNOWLEDGMENT

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REFERENCES

1. W. Mann. Discussion of Transportation Integrated Modeling System (TRIMS). Presented at 57th Annual Meeting, TRB, Jan. 1978.
2. N. Nihan and D. G. Miller. The Subarea Focusing Concept for Trip Distribution in the Puget Sound Region. TRB, Transportation Research Record 610, 1976, pp. 37-43.
3. C. Brown and Y. Gur. Adaptable Zone Transportation Assignment Package. Presented at 56th Annual Meeting, TRB, Jan. 1977.
4. John Hamburg and Associates and R. H. Pratt Associates. Functional Specifications for the North Central Texas Thoroughfare Planning System. North Central Texas Council of Governments, Arlington, TX, 1976.
5. S. Howe and Y. Gur. Trip Distribution in Subregional Analysis. TRB, Transportation Research Record 673, 1978, pp. 165-171.
6. S. Rosenbloom. Peak-Period Traffic Congestion: A State-of-the-Art Analysis and Evaluation of Effective Solutions. Transportation, Vol. 7, No. 2, 1978.
7. D. Morin. The Impact of Transportation System Management Strategies on Energy Conservation. Presented at 55th Annual Meeting, TRB, Jan. 1976.

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Priority Programming for Highway Reconstruction

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An adequacy rating procedure was developed for use in priority programming for highway reconstruction. The procedure makes use of 15 roadway and traffic elements to rate highway sections in urban and rural areas based on a 100-point scale. Condition elements (35 points) include a subjective rating of highway foundation, pavement surface, drainage, and maintenance economy. Safety elements (35 points) are stopping-sight distance, highway alignment, skid resistance, accident experience, and traffic-control devices. Service elements (30 points) include shoulder width, passing opportunity, rideability, surface width, volume-capacity ratio, and average speed. Some of the advantages of the new procedure include computerized analysis of all input data and detailed output summaries. All highway sections are referenced by milepoints, reference points, and federal-aid route numbers. The procedure incorporates the 1978 design standards. New adequacy concepts include the use of the rate-quality control method for accident analysis, a formal rating scheme for traffic-control devices, and a rating of lane width based on design level of service. Other advantages include measured skid numbers and a roadway-condition rating guide for subjective evaluations of six different roadway elements.

Virtually every state has a systematic procedure for periodic evaluation of highway sections for improvement programming. The procedure, known as adequacy ratings (or sufficiency ratings), was first developed and implemented by the Arizona Highway Department in 1946 (1). The rating of highway sections is generally based on a 100-point scale, where 100 points applies to a new section.

The adequacy rating includes the evaluation of several highway and traffic elements, which may be classified as condition, safety, or service. Condition elements usually require subjective evaluation and may include foundation, surface, shoulder, and drainage. Safety elements may include more objective information, such as surface width, accident information, stopping-sight distance (SSD), alignment, and skid resistance. Service elements may refer to such descriptors as rideability, passing opportunity, shoulder width, traffic speed, or volume-capacity (V/C) ratio.

A nationwide survey was published in March 1973 of the most commonly used variables considered in adequacy rating of highways (2). The point values most often used were 40 for condition, 30 for safety, and 30 for service. More than 80 different highway and traffic elements were found to be in use in the United States in adequacy ratings. The 16 most common elements were recommended for use with either 5 or 10 points assigned to