Transportation System Management—How Effective? Some Perspectives on Benefits and Impacts

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The process of transportation system management (TSM), the nature of its impacts, impact measures, and analysis techniques are described. The use of basic measures such as capacity, travel time, vehicle occupancy, accidents, transit ridership, and costs is emphasized, and it is shown how each can be estimated on the basis of analogy, published relationships, or analytical models. Impact measures are relatively few for any project, not universally required, and have specific interrelationships. Once the primary measures are computed, the secondary ones can be derived as necessary. Most TSM actions deal with localized improvements whose impacts are small in scale and difficult to estimate. Therefore impact assessment techniques should be direct, simple, and in scale with the problems involved, degree of accuracy required, and resources of the community. Impact assessment is a means, not an end. The main goal of TSM is improvement, not analysis.

Transportation system management (TSM) is in transition. Conceived in the mid-1970s as a way of making better use of existing transportation resources, its initial focus was on managing demand—more specifically, reducing automobile trips. Many analytical models were developed to estimate the likely reductions in travel due to demand management, and a broad range of performance measures was identified.

As TSM became more pragmatically oriented in ensuing years, the need to simplify analysis procedures and impact assessments became more apparent. This led to a "problem" focus of TSM, with solutions keyed to problems and use of simple, direct approaches to impact assessment *(1)*. Impact assessment became part of an iterative process that deals with problems, analysis, proposals, and programs.

The nature and scale of TSM impacts are reviewed, impact (performance) measures are suggested, and impact analysis techniques that can be used to assess potential problem solutions are described. The suggested approaches generally are easy to use, produce reasonable results, and focus on specific problems. They are consistent with the scale and needs of short-range actions and the resources of most transportation agencies.

THE TSM PROCESS

The key steps in the TSM planning process flow out of the problems and objectives for any given situation. They include analyzing the problem, identifying likely solutions, screening candidate actions, assessing performance (benefits and impacts), refining or combining actions or both, and developing improvement programs.

Analyze the Problem and Its Setting

The first step is to clearly identify the specific transportation or environmental problems, or both, to be addressed. Is it arterial street congestion along the main artery leading to the city center? Is it inadequate transit service within a growing residential area? Is it ineffective control of driveways along a suburban highway?

A field reconnaissance or "base conditions analysis" will prove useful in answering these questions and in pinpointing problems.

Identify Likely Solutions

Once the problems have been defined, possible solutions should be identified. The solutions should be consistent with the size and nature of the problems, for example, single intersection, entire street, major employment center, or entire region. This also makes it possible to bring appropriate agencies into the planning process and to assess the likely range of impacts.

Screen Actions

The candidate actions should be screened to see whether they are realistic in terms of actual land use, transportation system characteristics, and transportation needs. This may call for reviewing similar situations in the same town or in other communities to screen out obviously inappropriate measures. For example, a bus lane is not appropriate along a section of road that has neither buses nor congestion.

Assess Performance

Actions that survive the screening should be further analyzed in terms of how well they solve the problems. Analysis should focus on primary performance measures that influence transportation service and in turn affect energy consumption and air quality. The choice of primary measures will vary according to specific circumstances and actions, but normally will include

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• System use: number of vehicle and person trips by mode of travel [i.e., transit ridership, car occupancy, traffic volumes, vehicle miles of travel (VMT)]
• System capacity (vehicle and person)
• Service quality (travel times, delays, level of service or VMT)
• Accidents
• Costs (capital, operating, and maintenance)

These measures usually are computed directly. Fuel consumption and emissions can then be derived. Costs should be compared with benefits to see how effective the measures are.

Other relevant factors should be analyzed. Is the solution really workable? Does it reflect community preferences? Will it benefit or adversely affect surrounding shops and activities? What are its political implications?

Combine Actions

In many cases it will be necessary to combine related actions into groups to avoid transferring problems or to attain perceptible time and safety savings. The various impacts of these groups of actions should be reassessed as necessary.

Develop Improvement Program

The last step is to develop a staged improvement program that brings together recommended actions for each time period in a coordinated manner. This program should include schedules for implementation, including costs, responsibilities, and recommendations for supportive actions by various agencies. Assigning priorities should reflect

• Degree of problem and need
• Likely benefits
• Geographic equity
• Coordination with other projects
• Costs

THE NATURE OF TSM IMPACTS

There are important differences between the impact analysis for short-range low-cost improvements and that for long-range transportation improvements. The costs, extent of benefits, and likelihood of generating secondary impacts usually are less for TSM actions.

Impact Scale

Differences in travel time savings illustrate how TSM measures usually vary from major new construction. A new rail transit line might save 2 to 3 min of travel time per mile when it traverses an area that was previously without service. Thus, if it extends for 3 or 4 mi, the total time savings might exceed 10 min. (Chicago's Milwaukee Avenue subway, a diagonal line replacing two legs of a triangle, cut travel times from 22 to 10 min over a 3.5-mi run, a saving of more than 3 min/mi.) But TSM actions normally generate smaller unit time savings and extend for shorter distances. Thus, their total impacts are less.

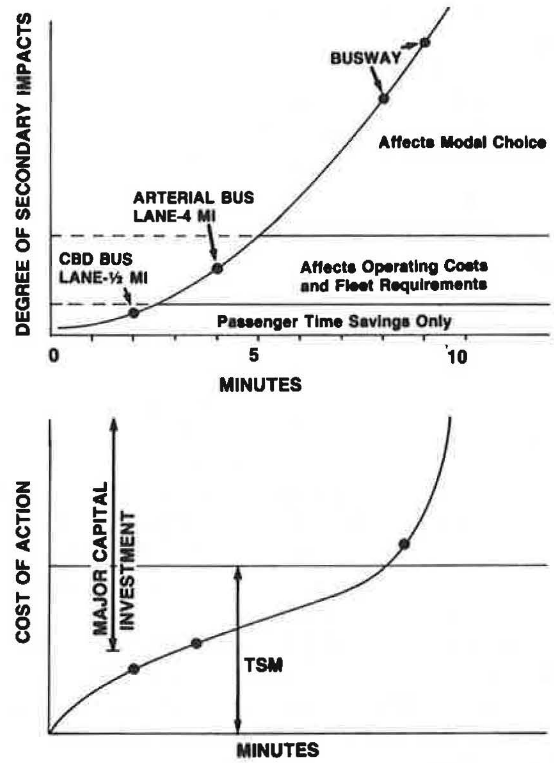

FIGURE 1 Example of impacts and costs.

A traffic signal system improvement that raises speeds from 20 to 30 mph saves 1 min/mi; if it extends for 2.5 mi, the aggregate saving is 2.5 min.

The differences between short- and long-range improvements are apparent from the conceptual relationships shown in Figure 1.

• A 1-mi central business district (CBD) bus lane may save up to 2 min. But this passenger time savings would be too small to modify fleet requirements or to induce changes in travel mode.
• A 4-mi arterial bus lane may save up to 4 min (e.g., 1 min/mi). This time savings might reduce fleet requirements and operating costs. But it is not likely to be perceived as significant on a 30-min trip, and therefore it would not affect ridership or mode-choice decisions.
• A new busway may save 8 min per trip. This time savings generally is sufficient to affect choice of mode. But such a facility normally lies outside the domain of low-cost TSM actions.

Thus, the impact analysis can be simplified once the scale of the primary impact is quantified. This is readily identified from the arterial street bus-lane analysis shown in Figure 2.

• A bus lane will have the primary effects of reducing bus passenger delay and possibly increasing automobile passenger delay. The primary measure becomes net reduction of person delay. This delay reduction is achieved for a certain cost, a second primary measure. (These primary measures are represented by solid lines.)
• If the bus lanes are implemented over an extended distance and the time savings are increased, bus fleet requirements

and operating costs would reduce. Ridership may or may not increase.

- Introducing service changes along with an extended bus-lane operation might increase ridership. The increased bus ridership conceivable could lead to reduced VMT and energy consumption, but in most cases it would not create measurable impacts in these areas.

Impact-Chain Concept

The choice of specific performance or impact assessment measures to use is simplified when the relationships between the primary measures and auxiliary measures are clarified. This is because any given action produces a sequence or chain of impacts. A few of these impacts are basic ones from which the other impacts can readily be calculated.

Consequently, most TSM analysis requires that only the few primary impacts on which the others depend be considered. Table 1 gives examples of impact chains. The numbers in the table denote, in ascending order, the sequence and relative dependency of impacts for each action.

For example, in assessing the effectiveness of widening an intersection (i.e., adding a left-turn storage lane), the basic impacts are increasing capacity and reducing accidents. Reduced delay (or better level of service) and hence reduced vehicle hours of travel (VHT) are a direct consequence of increasing capacity (and lowering the volume-to-capacity ratio). Finally, air quality and energy gains can be computed from the basic impacts.

The impact estimation chain provides a useful guide in planning and analysis. It enables the evaluation procedure to focus on measuring the one or two basic impacts for any given problem solution. This will vastly simplify the analysis, especially when resources are limited. The other measures in the chain can be derived where relevant, treated qualitatively, or otherwise ignored.

SELECTING PERFORMANCE MEASURES

Specific measures of impacts were selected from a review of existing TSM classification schemes, an analysis of candidate actions, a look at how measures relate to commonly encountered problems, and an appraisal of the capabilities of local transit, traffic, and planning staff. Emphasis was placed on the few significant performance measures that address goal achievement or problem solution with respect to the key issues of congestion, mobility, environment, energy, and safety.

A further simplification of the choice of measures is possible when the distinction is made among the three types of measures:

1. Basic measures can be directly estimated or obtained through data collection. These include such measures as capacity, travel time, number of accidents, car occupancy, and cost.
2. Derived measures depend on a basic measure for their calculation. Air quality and energy impacts are commonly derived from values for VMT or VHT. Level of service is derived from traffic signal timing and volume-to-capacity ratios.
3. Intermeasures show relationships between measures, that is, cost per person or minute saved or cost per VMT reduced. The intermeasures are useful in comparing the relative merits of different types of actions.

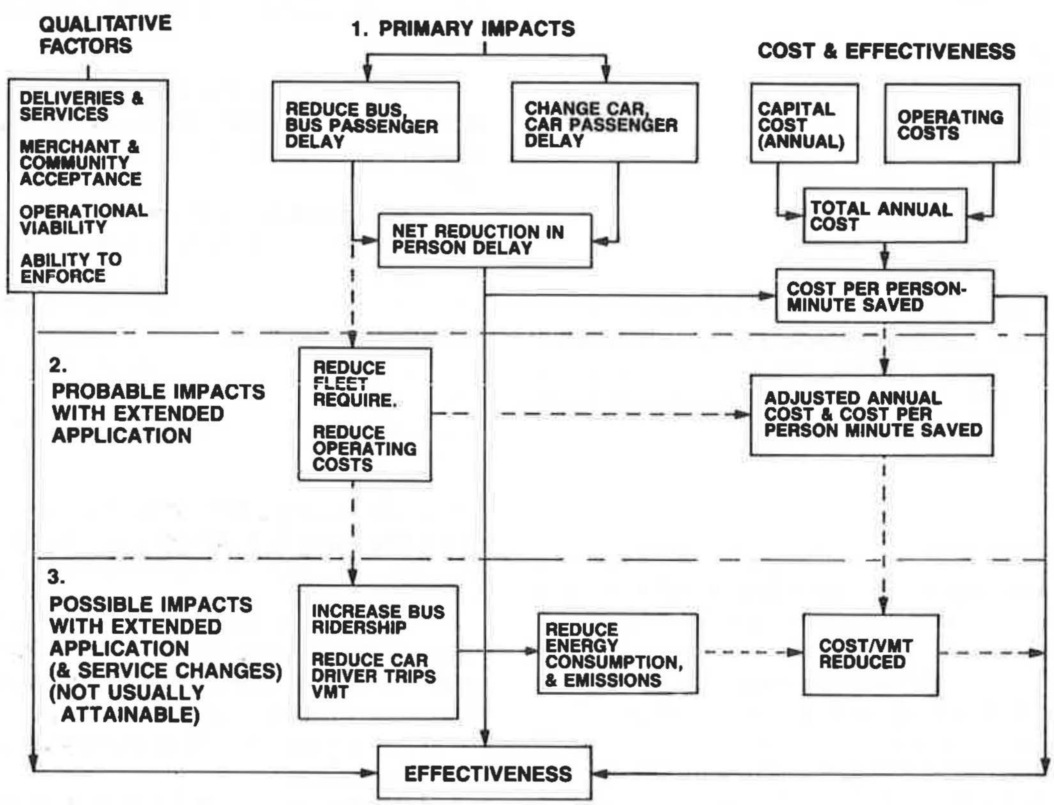

FIGURE 2 Bus-lane impact analysis.

TABLE 1 IMPACT-CHAIN CONCEPT: EXAMPLES

Goal or Impact	Carpool Program	Staggered Work Hours	Reduced CBD Parking Supply	Park-and-Ride Lot	Widened Intersection	Coordinated Traffic Signals	Metered Freeway Ramp	Arterial Bus Lane	Bus-Only Street	Expanded Busway Service
Increase capacity	–	–	–	–	1	–	1[a]	–	–	–
Reduce delay (save time)	–	3	2?	–	2	1	1	1[b]	1[c]	–
Reduce VHT	–	3[d]	3	2	2	2	2	3?	–	–
Reduce car trips	2	2	1	1	–	–	–	3?	3?	3?
Reduce VMT	3	2[d]	3	2	–	–	–	3?	3?	3?
Increase vehicle occupancy	1	–	–	–	–	–	–	3?	–	–
Reduce accidents	–	–	–	–	1	2	2	–	–	–
Improve transit access/service quality	–	2	–	–	–	–	–	2	–	1
Increase transit ridership	–	–	2	2	–	–	–	2?	2?	2
Reduce emissions	4	4[d]	4	3	3	3	3	4?	4?	4?
Reduce energy used	4	4[d]	4	3	3	3	3	4?	4?	4?
Change operating/maintenance costs	–	–	–	3	–	–	–	3	3	2
Change net subsidy	–	–	–	3	–	–	–	4	4	3
Other										
Reduce peak demand	2	1	–	–	–	–	–	–	–	–
Reduce transit equipment needs	–	2	–	–	–	–	–	–	–	–
Reduce equipment requirements	–	–	–	–	–	–	–	2	–	–
Improve CBD environment	–	–	–	–	–	–	–	–	?	–

NOTE: Numbers denote sequence of impacts. Impact 1 is basic. Impact 2 depends on 1, 3 on 2, and so on. Question mark denotes possible impact. Dashes indicate data not applicable.

[a] Through-lane capacity.
[b] Person.
[c] Bus.
[d] Peak.

SOURCE: H. S. Levinson, unpublished data.

Measures in each category are listed in Table 2. These measures are generally applicable, easily understood, readily quantified, and adaptable to statistical analysis.

The basic measures require data collection or direct estimation. They include the following:

Traffic volume or person flow, from which VMT or person-miles of travel (PMT) can be derived.

Capacity, expressed as persons or vehicles per hour or vehicles per mile (freeway), from which level of service can be derived.

Travel time, expressed as minutes per mile or average speed, from which vehicle or person-hours of travel (PHT) can be derived. Vehicle-hours of delay is a related measure.

Average vehicle occupancy (persons/vehicle).

Safety, expressed as total accidents, from which accident rates can be derived (i.e., accidents per 100 million VMT).

Transit service quality, expressed in terms of service provided and load factors.

Transit ridership, total daily or annual riders by line or system, which can be correlated with the transit hours or miles provided or with the population in the service area.

Capital cost, total and annualized.

Operating and maintenance costs (cost per bus hour or bus mile).

The derived measures depend on the basic measures, such as traffic volumes and speeds:

Level of service is derived from volume-to-capacity ratios, traffic flow densities, or traffic signal timing, or from all three.

Air quality, expressed in terms of the amount of pollutants emitted, depends on traffic volumes and speeds.

Energy consumption, expressed in gallons of gasoline or British thermal units (BTUs) per person or vehicle mile, also depends on traffic flow conditions.

The intermeasures reflect the cost per unit of attainment:

Annual cost per person-minute saved or per VMT reduced.
Gallons of fuel saved per dollar spent or per VMT reduced.

Qualitative factors should also be considered in assessing improvement effectiveness. Will the improvement work? Will it enhance the environment? Will the community accept it? Can it be maintained and enforced? Is it politically feasible? These qualitative factors are commonly viewed as secondary measures, but sometimes they may dominate the decision. They underlie TSM actions such as pedestrian malls or residential street enhancement.

Finally it should be realized that these measures will not apply to every specific problem. The relevance of each will depend on the nature of the problem, goal, or action. A pedestrian mall may improve retail sales, but it will not improve on-time bus performance. Reducing overcrowding on transit vehicles will have little impact on VMT or VHT. A carpool program probably will not affect existing road capacity. The average vehicle occupancy is not meaningful in assessing impact of traffic signal timing changes or intersection improvements. It is necessary to choose the appropriate primary and secondary measures and to discard those that do not apply.

SELECTING IMPACT ASSESSMENT TECHNIQUES

Discussions with public agencies and reviews of the literature produced a broad range of impact assessment techniques. The following criteria should influence selecting and evaluating techniques:

Does the technique provide accurate, reliable, and, above all, reasonable estimates?

Are the estimates consistent with the definition and level of detail needed for the desired impact?

Is the technique sensitive to the scale of the TSM action?

Does the technique account for interactions among different TSM actions that might be implemented as a group or package?

Can the estimates be used directly to assess the effectiveness of TSM actions, or must the estimates be transformed?

Are the data requirements of the technique within the existing resources of identified classes of users, or are special collection efforts required?

Does application of the technique by many users require the assistance of other agencies?

Does the staff of most public agencies have the time and skills necessary to learn and understand the technique?

Is an application of the technique easy to document, allowing the quick assessment by other staff of changes and refinements of proposed TSM actions?

Can the technique be applied (including any necessary calibration steps) within the time limitations imposed by meeting, hearing, and documentation schedules?

In sum, estimation methods should be easy to use, produce

TABLE 2 PRINCIPAL PERFORMANCE MEASURES

Measure	Parameter	Remarks
Basic		
Capacity	Persons/hour, vehicles/hour or passengers/car unit/hour, vehicles/mile (freeways)	Base on peak 15-min flow rate
Travel time	Minutes/mile, vehicle hours of travel (VHT), person-hours of travel (PHT), delay (sec/person or vehicle), average speed	Applies to cars and transit
Vehicle miles of travel (VMT)	Volume (i.e., car trips), volume times distance	Volume is a basic input or surrogate
Average vehicle occupancy	Persons/car, persons/transit vehicle	–
Safety	Accidents/year, accidents/100 million VMT, accidents/vehicle entering, intersection or volume product	May refine by type or severity of accident or both
Transit service quality	Coverage (percentage of population within 1/4 or 1/2 mi), passengers/seat or ft^2/passenger, peak and off-peak; bus miles/1,000 residents	Transit travel time is a complementary measure
Transit ridership	Daily or annual riders (annual rides/capita in service area, daily riders/bus mile or bus hour)	–
Capital cost	Annualized capital cost in dollars	–
Operating and maintenance cost	Annual cost in dollars (cost/bus or car mile, cost/bus or car hour)	Employees/transit vehicle is surrogate
Net cost of service	Annual transit subsidy in dollars, percentage of operating costs covered by fares (subsidy per passenger in cents)	Similar measures apply for parking facilities; key factor is coverage ratio: net annual income to annual debt service
Derived		
Air quality	Emissions in grams of HC, CO, NO_2 (emissions/mile)	Volume/speed or volume × (min/mi) is a good surrogate
Energy	Gallons of gasoline, BTUs (megajoules), BTUs/vehicle mile (BTUs/person mile)	–
Level of service	Avg stopped delay or vehicles per mile	–
Intermeasures		
Annual cost/unit of attainment	Cost/increase in vehicle or person capacity, cost/person or vehicle minute saved, cost/increase in transit ridership (i.e., cost per additional rider), cost/accident reduced, cost/VMT reduced, cost/gallon saved	–
Benefit-cost ratio	Discounted ratio of benefits to costs	–

SOURCE: H. S. Levinson, unpublished data.

TABLE 3 PRINCIPAL IMPACT TECHNIQUES KEYED TO PERFORMANCE MEASURES

Performance Measure	Impact Techniques
Capacity	2, 3
Travel time	1, 2, 3, 4, 11
Vehicle volume/VMT	5, 6
Avg vehicle occupancy	1, 11
Safety	1, 2, 11
Transit service quality	2, 3, 6, 7
Transit ridership (mode share)	1, 5, 6, 11
Air quality (emissions)	9
Energy	10
Capital cost	1, 12
Operating and maintenance cost	8
Net cost of service	2, 6, 8
Level of service	3, 4

NOTE: Impact techniques are as follows: (1) analogy and experience, (2) design specification, (3) capacity analysis, (4) speed-flow analysis, (5) mode-choice models, (6) elasticity factors, (7) transit performance analysis, (8) transit operating and maintenance cost analysis, (9) speed versus emissions, (10) speed versus fuel consumption, (11) before-and-after statistical comparison, and (12) engineering cost estimates.

reasonable results, and provide reliable answers (estimates) to specific problems.

The major impact assessment techniques can be grouped into three overall categories that reflect the amount of information available.

1. For situations in which detailed local data are available, equations or analytical models can be applied to predict impacts directly. Procedures in this category include modal-choice analysis, pivot-point procedures, and selective disaggregate behavioral demand modeling. These techniques are most accurate where they directly relate impacts to system characteristics or to changes in these characteristics. Yet, for many TSM actions, the cost of application is not justified by the low-cost nature of the action itself.
2. Where less local information is available but statistically valid information on observed results has been synthesized, tabular values or graphs showing a range of experience can be applied. Care must be taken in using these techniques to be sure that the local conditions are comparable with those reported.
3. For TSM actions that have not been extensively applied (as is often the case), the existing data base is insufficient for the calibration of models or relationships to directly predict their impacts. For such actions or impacts, therefore, an "analogy" approach can be used, transferring data from a limited number of case studies to illustrate general impacts. The analogy method is useful in many cases either to predict general impacts or to verify the impacts obtained from analytical methods.

The principal impact techniques can be grouped into the following categories: analogy and experience, design specification (i.e., specifying future performance), capacity analysis, speed-flow relationships, mode-choice models, elasticity factors, transit performance analysis, transit operating and maintenance cost analysis, speed-emission-energy relationships, statistical tests that compare before-and-after conditions, and engineering cost estimates. Table 3 shows how these techniques relate to the various performance measures.

Analogy and Experience

Available experience provides a powerful tool for assessing impacts of most improvements. This method includes a broad array of look-up tables and charts that summarize and synthesize the state of the art. Site-specific parameters can transfer one community's impacts to an analogous situation. Analogy is the most practical method for assessing changes in accident rates, that is, accident reduction factors. It is also valuable in providing first-order estimates of installation costs. Typical examples include reported time savings for a one-way street system, likely market penetration of a staggered-hours program, and the increased vehicle occupancy resulting from a high-occupancy-vehicle (HOV) lane. An example is given in Table 4, which shows costs of freeway priority-lane projects.

Design Specification

In the design approach, the impacts are inherent in the solution; that is, standards desired for a particular improvement are based on design or simulation. Net benefit or change is then estimated by comparison with existing conditions. This approach is commonly applied to actions that involve transit or traffic improvements.

For example, average travel times along an arterial street might approximate 3.5 min/mi. A time-space diagram analysis of a coordinated traffic signal system would yield progressive speeds of 30 mph, or 2 min/mi. The anticipated savings would amount to 1.5 min/mi.

Capacity Analysis

Values, relationships, and adjustment factors for highways, transit and pedestrian capacities, and service levels are set forth in the 1985 *Highway Capacity Manual (3)*. Techniques for signalized intersections include both capacity computations and level-of-service analysis.

- The capacity of any lane group at a signalized intersection depends on the number of effective moving lanes, traffic signal timing, and saturation flows (or vehicle headways).
- The level of service is defined by the average stopped delay in seconds per vehicle. The delay depends on the volume-to-capacity ratio, traffic signal cycle length, green time, and the quality of the traffic signal progression.
- Changes in intersection capacity can be approximated by comparing the lane-seconds of green available before and after an improvement.

Speed-Flow Relationships

Speed-flow relationships based on the 1985 *Highway Capacity Manual* and earlier editions of this manual show how speeds decrease as the volume-to-capacity ratios increase. They can be

TABLE 4 COSTS OF FREEWAY PRIORITY-LANE PROJECTS (2, p. 45)

Project	Capital Cost ($)	Cost per Mile ($)	Annual Operations and Maintenance Cost ($)
With-flow lanes			
Boston, Southeast Expressway	91,500	11,400	194,000
Los Angeles, Santa Monica Freeway	163,000,[a]	13.000	
	358,000[b]		Unknown
San Francisco, US-101	25,000[a]	7,000	Negligible
Miami, I-95	18,500,000[c]	2,500,000	88,000
Honolulu, Moanalua Freeway	10,000[a]	3,700	Negligible
San Francisco, Oakland Bay Bridge	50,000[a]		
	350,000[d]		28,000
Portland, Banfield Freeway	2,100,000[e]	780,000	Unknown
Contraflow lanes			
Boston, Southeast Expressway	40,000	5,000	137,500
New York, I-495 Lincoln Tunnel Approach	700,000	280,000	200,000
New York, Long Island Expressway	44,000	22,000	150,000
San Francisco, US-101	180,000	45,000	60,000
Separated HOV express lanes			
Washington, D.C., Shirley Highway	28,000,000–43,000,000[f]	2,500,000–4,000,000	Unknown
San Bernardino busway	56,000,000[g]	5,000,000	Unknown

[a]Signing and marking.
[b]Marketing.
[c]Including freeway widening but excluding park-and-ride lot.
[d]Special signal system.
[e]Includes freeway widening and other roadway improvements.
[f]Depending on assumptions.
[g]Including park-and-ride lot.

used to estimate the changes in travel time (minutes per mile) resulting from expanding capacity or reducing demand. They also provide input for energy and air quality impact analysis.

Table 5 shows how the travel time on freeways increases as the volume (or volume-to-capacity ratio) increases for 50, 60, and 70 mph average design speeds. An example is as follows: For a design speed of 70 mph and a *V/C* ratio of 0.60, the average travel time is 1.05 min/mi. If the *V/C* ratio increases to 0.80, the average travel time rises to 1.15 min/mi.

Mode-Choice Estimates

The choice of travel mode can be estimated by a variety of methods. These include full mode-choice models, direct-demand estimates, pivot-point methods, and elasticity factors.

Mode-Choice Models

The mode-choice models normally require detailed origin-destination information and detailed descriptions of travel times, costs, and utilities for each trip interchange. They are best suited for long-range demand forecasting, although they may be useful in testing areawide transportation system policies. However, from the perspective of obtaining quick, meaningful, and realistic assessments of localized, fine-grained changes, they do not appear practical. The many assumptions and weights associated with estimating disutilities, as well as the cost and complexity of their application, further limit their usefulness for early action, low-cost service changes. Thus, the use of full mode-choice models is warranted only when actions are expected to produce major changes in existing services or when major new services are introduced.

Direct-Demand Estimates

Direct demand is estimated when new service is introduced to a corridor or area and when transit ridership is expected to have minimum impact on automobile trips. The method calls for

TABLE 5 FREEWAY SPEED-FLOW RELATIONSHIPS: TRAVEL TIME VERSUS VOLUME–CAPACITY RATIO (3, Table 2-5)

Passenger Cars/Lane/ Hour	Volume-to-Capacity Ratio	Estimated Minutes per Mile by Design Speed: 70 mph	60 mph	50 mph
800	0.40	0.97	1.16	1.29
900	0.45	0.99	1.18	1.31
1,000	0.50	1.07	1.20	1.33
1,100	0.55	1.03	1.22	1.35
1,200	0.60	1.05	1.24	1.37
1,300	0.65	1.07	1.26	1.39
1,400	0.70	1.09	1.29	1.42
1,500	0.75	1.11	1.34	1.45
1,600	0.80	1.15	1.39	1.48
1,700	0.85	1.20	1.45	1.56
1,800	0.90	1.27	1.62	1.71
1,900	0.95	1.42	1.79	1.90
2,000	1.00	2.00	2.00	2.14
2,000+[a]	>1.00	3.00	–	–

[a]Assumed for breakdown conditions or future demand conditions.

estimating the number of people in the proposed service area and their likelihood of riding transit *(4)*. Market and employer surveys and analogy methods will prove useful in estimating the market penetration of the new transit service.

Elasticity Factors

Elasticity factors can be used to assess the impact of changes in transit service, fares, or parking costs. The factors are easy to understand and use and provide a quick response to particular transportation changes in which minor to moderate impacts are expected. Care should be exercised in their use because of the wide range of particular factors from place to place and, in some cases, the limited data base. A 100 percent increase in fares, headways, population coverage, or bus miles is likely to produce the following changes in transit ridership based on current experience:

Type of Increase	*Change in Ridership (%)*
Fares	−40
Headway	−40 to −60
Coverage	+60 to +90
Bus miles	+70 to +100

Transit Performance Analysis

Existing transit performance can be based on field observations of speeds and delays, running-time checks, and passenger counts at maximum load points. Future performance can be estimated by assuming changes in key variables. The values shown in Table 6 can be used to estimate the effects of reduced traffic congestion or frequency of stops.

Transit Operating and Maintenance Cost Analysis

Operating and maintenance costs are specific to a given community at a given point in time. Transit operating costs, in particular, must be kept current to reflect changes in wage rates and fuel prices. Transit costs can be estimated by two basic methods or models:

1. Costs can be allocated to bus (or rail car) hours, bus or car miles, or peak vehicles, or all three. One-, two-, or three-variable equations can be derived of the form Cost = A (bus hours) + B (bus miles) + C (peak vehicles). This is the most common method, although it may not accurately estimate the costs of small-scale system changes.
2. Costs can be allocated to drivers (trainmen) and bus or car miles. This approach provides relatively precise cost estimates whenever service changes require extra drivers and vehicles:

Cost = (drivers) × (wage rate/driver) + bus miles × [nondriver costs/bus (car) mile]

Operating and maintenance costs for bus priority facilities, reversible-lane operations, carpooling programs, and other actions can be estimated from current experience.

Speed-Emission-Energy Relationships

Air quality and energy benefits are realized whenever the amount of travel, travel times, or traffic densities decrease. This calls for estimating the travel-time savings of specific improvements. Such estimates can be based on (a) direct before-and-after studies of actual conditions, (b) expected benefits of specific actions, or (c) V/C–travel-time relationships.

Illustrative relationships among average speed, fuel consumption, and emissions are shown in Table 7. Tables such as this can be used to estimate the energy and air quality savings from improvements in street system efficiency. Table 7 shows that an increase in speed from 15 to 20 mph would

- Save 1.0 min/mi.
- Reduce fuel consumption from 0.0825 to 0.0725 gal/mi, a savings of 0.0100 gal/mi.

TABLE 6 BUS TRAVEL TIMES AND SPEEDS AS A FUNCTION OF STOP SPACING AND TRAFFIC CONGESTION

				With Traffic Delays (peak conditions)					
		Without Traffic Delays		Central Business District: 3.0 min/mi delay		Central City: 0.9 min/mi delay		Suburban: 0.7 min/mi delay	
Time per Stop (sec)	Stops per Mile	Travel Time (min/mi)	Speed (mph)	Travel Time (min/mi)	Speed (mph)	Travel Time (min/mi)	Speed (mph)	Travel Time (min/mi)	Speed (mph)
10	2	2.40	25.0	5.40	11.1	33.30	18.2	3.10	19.4
	4	3.27	18.3	6.27	9.6	4.17	14.4	3.97	15.1
	6	4.30	14.0	7.30	8.2	5.20	11.5	5.00	12.0
	8	5.33	11.3	8.33	7.2	6.23	9.6	6.03	10.0
	10	7.00	8.6	10.00	6.0	7.90	7.6	7.70	7.8
20	2	2.73	22.0	5.73	10.5	3.63	16.5	3.43	17.5
	4	3.93	15.3	6.93	8.8	4.83	12.4	4.63	13.0
	6	5.30	11.3	8.30	7.2	6.20	9.7	6.00	10.0
	8	6.67	9.0	9.97	6.0	7.57	7.9	7.37	8.1
	10	8.67	6.9	11.67	5.1	9.57	6.3	9.37	6.4
30	2	3.07	19.5	6.07	9.9	3.97	15.1	3.77	15.9
	4	4.60	13.0	7.60	7.9	5.50	10.9	5.30	11.3
	6	6.30	4.5	9.30	6.5	7.20	8.3	7.00	8.6
	8	8.00	7.5	11.00	5.5	8.90	6.7	8.70	6.9
	10	10.33	5.8	13.33	4.5	11.23	5.3	11.03	5.4

SOURCE: H. S. Levinson, unpublished data.

TABLE 7 EFFECT OF SPEED ON ENERGY AND AIR QUALITY *(5, 6)*

Avg Speed (mph)	Avg Travel-Time Rate (min/mi)	Fuel[a] Economy (mpg)	Fuel Consumption Rate (gal/mi)	1977 Emissions (g/mi)		
				NMHC	CO	NOx
10	6	9.76	0.1025	6.8	95.6	20.5
12	5	10.8	0.0925	5.8	80.0	2.5
15	4	12.1	0.0825	4.7	63.9	2.6
20	3	13.8	0.0725	3.8	49.4	2.8
25	2.4	15.0	0.0665	3.2	40.3	3.0
30	2	16.0	0.0625	2.7	33.4	3.2
35	1.7	16.7	0.0060	2.4	28.3	3.3
40	1.5	17.4	0.0575	2.1	24.8	3.4

[a]Based on composite VMT-weighted mix of automobile weights in the 1976 U.S. fleet. Not corrected for cold starts.

- Reduce HC emissions from 4.7 to 3.8 g/mi, a savings of 0.9 g/mi.
- Reduce CO emissions from 63.9 to 49.4 g/mi, a savings of 14.5 g/mi.
- Increase NOx from 2.6 to 2.8 g/mi, a gain of 0.2 g/mi.

This table is straightforward to use and provides a good order-of-magnitude assessment of impacts. Detailed emission and fuel consumption factors by vehicle type, speed, and temperature are available and should be used when greater accuracy is desired. Methods are also available for estimation of impacts of starts and stops. In assessing impacts, it is important to use the most recent data on the highway and bus fleets.

Before-and-After Statistical Comparisons

Before-and-after comparisons are important to show community leaders and the general public the benefits of improvements and thereby attain support for improvement programs and to assess the statistical significance of specific improvements or improvement programs. Published before-and-after studies, such as those distributed through UMTA's Service and Methods Demonstration Program, provide a good basis for analogy models.

Engineering Cost Estimates

Initial estimates of capital and operating costs can be obtained from previous estimates for similar projects or from information contained in *Characteristics of Urban Transportation Systems (7)* or similar documents. However, because costs vary with each specific project, care should be exercised in transferring cost data. Ideally, cost estimates should be site specific.

APPLYING ANALYSIS TECHNIQUES

The choice of methods and application procedures will depend on the intended use of the results and on the information base and other resources available for estimating the performance and impact measures required for design and evaluation. Limited data, planning budgets, time, staff availability, skills and experience, and access to computers all place restrictions on the methods and procedures that can be applied. The restrictions are usually apparent, although the best approaches to dealing with them may not be.

A general guide is to quantify as few impacts as necessary. However, relevant qualitative factors should be carefully considered.

The level of detail and desired accuracy will be influenced by factors such as these:

1. Size of likely impact: Small changes in performance and other measures are difficult to predict with confidence; they are often smaller than the errors inherent in both the estimation procedure and the observed data.
2. Sensitivity of design features: Capacity measures vary in sensitivity to estimated values as a result of their nature. A crude estimate of patronage, for example, might indicate that two buses were required for a suburban feeder service. If that service design does not change with a 40 percent lower or higher estimate of patronage, the crude estimate is adequate for the analysis.
3. Scale of action: More accurate estimates are generally required for expensive actions or actions with relatively long service lives, because mistakes in changing these actions are likely to be costly or difficult to remedy.
4. Ability to fine tune: Many TSM actions can be modified after implementation when direct measurements of performance can be made.
5. Trade-offs among impacts: Changes in transportation performance may create adverse impacts that should also be identified. One example is removing curb parking to create a bus lane along a street that has many small shops and no off-street parking. Conversely, a pedestrian street will improve the amenity, but it may affect goods delivery and parking garage access.

EFFECTIVENESS OF TSM

The effectiveness of TSM actions has varied widely. The potential time savings generally depends on the amount of congestion experienced before an improvement has been implemented. The greater the congestion, the greater the benefits. Coordinating traffic signals for a 30-mph progression will save 4 min/mi if the initial speed was 10 mph, but only 1 min/mi when the initial speed was 20 mph.

Examples of impacts estimated from a literature review, ongoing studies, and actual experience are the following:

1. Person and vehicle capacity gains
   On-street parking controls, 50 to 100 percent;
   General traffic improvements (typical), 10 to 20 percent; and
   Express transit service, 0 to 20 percent.
2. Travel-time savings
   Bus malls, 2 to 5 min/mi;
   Bus lanes on city streets, 1 to 5 min/mi;
   On-street parking controls, 0.2 to 2.4 min/mi;
   Traffic signal improvements, 0.4 to 1.6 min/mi;
   Bus lanes on freeways, 0 to 1.2 min/mi;
   General traffic improvements, 10 to 20 percent;
   Bus lane around major queue, 3 to 5 min;
   One-way toll collection, 2 to 3 min/car;
   HOV ramp bypass, 1 to 3 min/vehicle;
   Transit service coordination, 0 to 12 min/trip; and
   Express transit service, 2 to 5 min/trip.
3. VMT reductions (estimates)
   Automobile-free zone, up to 20 percent reduction across screenline;
   Bridge tunnel tolls, 2 to 5 percent reduction per affected crossing;
   Gas tax (+$0.10), 2 percent areawide reduction; and
   Areawide surcharge of $0.50 on licenses, 0.7 to 1.3 percent reduction (Manhattan).
4. Cost-effectiveness
   Carpools, $20 to $51/pool;
   Traffic signals, 2¢/VHT reduced;
   Staggered work periods, 25¢/VHT reduced (suburbs);
   Ramp metering, $1.00/VHT reduced; and
   Park-and-ride, 2 to 3.5¢/VMT reduced.

These examples provide a guide for making initial estimates and checking detailed calculations for reasonableness. Significant findings are as follows:

- Many actions have major impacts over a very localized area. It is hard to derive areawide impacts from the application of these actions, although site-specific impacts can be readily quantified.
- Traffic engineering improvements can increase capacity up to 100 percent, with 10 to 20 percent gains common. Travel-time reductions of 20 percent can translate into energy and air quality benefits.
- Demand management measures can achieve reductions in VMT up to 5 percent at specific locations on the basis of theoretical studies of travel elasticities and carpool formation. An effective ridesharing program, for example, would reduce VMT an estimated 0.2 percent in suburban areas and 0.1 percent in a large city like New York or Chicago; costs would average about 2¢/VMT reduced and about $20 to $50 per capita.
- Bus lanes can save bus passengers from 1 to 5 min/mi, depending on the amount of congestion.
- Bus bypass lanes at multilane freeway ramps will save bus passengers from 1 to 3 min per ramp, depending on the amount of congestion.
- Transit improvements will increase ridership, but at a rate less than the amount of additional service provided. A 2 percent gain in bus mileage would result in a 1 to 1.5 percent gain in riders, of which up to about one-half might be former motorists. Express transit extensions could increase corridor passenger capacity up to 20 percent and save passengers 2 to 5 min per trip.

IMPACTS IN PERSPECTIVE

In the preceding sections key impacts to be assessed have been identified and the commonly used methods for assessing benefits and impacts have been reviewed. The approaches provide a realistic basis for screening and evaluating options and, in a broader sense, formulating coordinated improvement programs.

The suggested impacts focus on basic factors such as capacity, travel time, accidents, transit ridership, and costs. The use of as few measures as possible is desirable to simplify rather than to complicate the evaluation process. The impact-chain concept supports this approach and provides one means to identify the few primary impacts that should be measured.

Impact measures are relatively few in number for any project, are not universally required for all problems, have a sequence of importance that varies according to the problem, and have specific interactions that enable a large subset to be derived from a few basic measures.

The effects of traffic engineering actions on speed, delay, and accidents are well documented in terms of both experience and analytical approaches. Transit ridership estimates can be derived from elasticity data, although there may be variations in the results. Actions that involve restraining or reducing motor vehicle travel have not been implemented in most cities, and the models used to predict their impacts give widely varying results. The data base for assessing impacts by analogy or by comparison with similar situations is limited.

There is need to expand the existing data base in three important ways: (a) better compilation of before-and-after experience of various improvements, (b) improved stratification of accidents by type and road or traffic condition, and (c) good capital cost data. More information of this type is needed to promote the benefits of specific actions.

Most TSM actions deal with localized improvements that involve fine-grained changes to the transportation system. Their impacts are small in scale and may be difficult to estimate in practice, and their statistical significance cannot be detected.

Impact assessment techniques, therefore, should be in scale with both the problems and the resources of the community. Simplicity and responsiveness are the underlying themes. Impact assessment is a means, not an end.

This implies adopting pragmatic approaches to identifying and assessing actions and formulating coordinated improvement programs. It calls for translating concepts and analysis into productive improvements, for viewing TSM as an action program, not merely as a planning process. It calls for streamlining the impact analysis by using methods that are consistent with the degree of accuracy required and the capabilities of communities.

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