Time-of-Day Modeling Procedures State-of-the-Art, State-of-the-Practice

October 1997

TMIP

Travel Model Improvement Program

Department of Transportation
Federal Highway Administration
Bureau of Transportation Statistics
Federal Transit Administration
Assistant Secretary for Transportation Analysis

Environmental Protection Agency

U.S. Department of Transportation

U.S. Environmental Protection Agency

Travel Model Improvements Program

The Department of Transportation, in cooperation with the Environmental Protection Agency and the Department of Energy, has embarked on a research program to respond to the requirements of the Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act of 1991. This program addresses the linkage of transportation to air quality, energy, economic growth, land use and the overall quality of life. The program addresses both analytic tools and the integration of these tools into the planning process to better support decision makers. The program has the following objectives:

1. To increase the ability of existing travel forecasting procedures to respond to emerging issues including; environmental concerns, growth management, and lifestyles along with traditional transportation issues,

2. To redesign the travel forecasting process to reflect changes in behavior, to respond to greater information needs placed on the forecasting process and to take advantage of changes in data collection technology, and

3. To integrate the forecasting techniques into the decision making process, providing better understanding of the effects of transportation improvements and allowing decision makers in state governments, local governments, transit operators, metropolitan planning organizations and environmental agencies the capability of making improved transportation decisions.

This program was funded through the Travel Model Improvement Program.

Further information about the Travel Model Improvement Program may be obtained by writing to:

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Prepared for
US Department of Transportation
Federal Transit Administration
Federal Highway Administration
Office of the Secretary
US Environmental Protection Agency

Executive Summary

In recent years, there has been increasing interest in the ability of travel demand models to estimate travel not only for the average weekday, but for different periods within the day. Travel demand models are increasingly required to be analysis tools for a broad range of issues on transportation policy and project alternatives. These issues often require detailed analysis, not only spatially, but temporally as well. This report provides documentation on methods used in U.S. urban areas to handle the issue of time of day in their travel demand models. Commonly used practices are described, the most innovative methods used by metropolitan planning organizations and states are documented, and emerging approaches are described as well.

■ Standard Approaches

Trips occur at different rates at different times of the day. Typically, there are one or more peaks in daily travel. The dominant weekday peak periods are in the morning (AM peak period) and in the late afternoon (PM peak period). A peak period can be characterized by its maximum trip rate (in trips per unit time). The peak hour is the hour during which the maximum traffic occurs. The portions of the peak before and after the peak hour are called the "shoulders of the peak."

The time at which travel occurs and, more specifically, travel peaking intensity and duration are critical to the estimation of a number of important travel performance measures, including speeds, congestion, and emissions. Yet peaking and time of travel are included in the traditional travel model in highly approximate ways, typically by developing peaking or time-of-day factors from observed data and assuming the same patterns will persist in the future.

A time-of-day factor (TODF) is the ratio of vehicle trips made in a peak period (or peak hour) to vehicle trips in some given base period, usually a day. Time-of-day factors are most commonly specified as exogenous values that are fixed and independent of congestion levels. If applied prior to trip assignment these time-of-day factors are usually determined from household activity/travel survey data and from on-board transit and intercept auto surveys, with a separate TODF for each trip purpose. If applied after assignment, the peaks' timing and duration are generally estimated from traffic data (e.g., 24-hour machine counts on streets and highways, transit counts, or truck counts), perhaps interpreted and adjusted based on data from special studies (e.g., travel surveys of workplaces and customer-serving businesses in a particular area or driveway counts at major activity centers). Occasionally, time-of-day factors are borrowed from other areas and adjusted during the model calibration process.

There are several commonly employed methods which account for time of day of travel in the four-step travel modeling process. To proceed from the initial daily trip generation estimates to the volume estimates by time period, average daily travel estimates must be converted to trips by time period. This time-of-day (TOD) assignment can happen at four places in the modeling process:

- After trip assignment;
- Between mode choice and trip assignment;
- Between trip distribution and mode choice; and
- Between trip generation and trip distribution.

These four time-of-day assignment approaches are described in the following paragraphs. Table ES.1 summarizes their applicability, level of effort and data required, and their limitations and advantages.

Time-of-Day Assignment after Trip Assignment

In this method, the assigned daily link volumes are factored to produce volume estimates by time of day. This method is the simplest and probably the most commonly used. The post-assignment static technique uses a daily traffic assignment as a basis. In its simplest form, peak hour factors (usually in the range of 8 to 12 percent) are used to reflect peak period link-level travel demand. In this approach, the daily assigned volumes are multiplied by the peak period factor to estimate peak period demands. The technique can be refined to reflect different peak hour percentages. A directional split percentage (e.g., 60 percent), derived from observed traffic conditions, is applied to obtain link-level peak volumes.

This procedure yields only a rough approximation of link- or corridor-level peaking though it may suffice for smaller Metropolitan Planning Organizations (MPOs) where the duration and intensity of congestion are limited. In general, there is little reason to expect specific facilities to exhibit the same peaking patterns or characteristics as "regional averages," and application of a fixed TODF may be a significant source of error.

Time-of-Day Assignment between Mode Choice and Trip Assignment

This widely used procedure factors the purpose- and mode-specific daily trip tables produced by the mode choice model. These trip tables are then used as inputs to time period-specific trip assignments. For example, three time periods may be used: morning peak, afternoon peak, and off-peak. Peak hours, rather than peak periods, are modeled in some regions. Daily traffic volumes are produced by adding up the results of the morning, afternoon, and off-peak period traffic assignments.

The process for preparing peak hour directional trip tables requires the factoring of the person or vehicle production-attraction formatted trip tables to peak hour (or period) origin-destination formatted vehicle trip tables. The data required include an hourly

Table ES.1 Time of Day Assignments

Method	Applicability	Level of Effort and Data Required	Limitations and Advantages
TOD Assignment after Trip Assignment	• Method may be sufficient for smaller Metropolitan Planning Organizations where the duration and intensity of congestion are limited • Most commonly used and simplest method	• Simplest method • Minimal labor and data required • Data required include peak hour factors that reflect peak period link-level travel demand; Directional split factors are also required	• Does not consider peak travel times in assignments • Trip distribution and mode split done without accounting for congested times • Does not account for localized effects of changes in demand
TOD Assignment between Mode Choice and Trip Assignment	• Method may be applicable in the least congested areas • Widely used method	• Data required include factors representing the percentages of the trips (by purpose and by mode) during each hour and for each direction, production-to-attraction or attraction-to-production; Directional split factors are also required	• Trip distribution and mode split done without accounting for congested times • Lack of sensitivity to general policy changes, increasing congestion levels, and corridor or subarea-specific changes
TOD Assignment between Trip Distribution and Mode Choice	• Method may be applicable in the least congested areas • Limited use	• Data required include factors representing the percentages of the trips (by purpose) during each hour and for each direction, production-to-attraction or attraction-to-production; Directional split factors are also required	• The effects of time of day characteristics such as congestion or transit levels of service are ignored in the way trips are allocated to time periods • Trip distribution and mode split done without accounting for congested times
TOD Assignment between Trip Generation and Trip Distribution	• Method may be applicable in the least congested areas • Limited use	• Data required include factors representing the percentages of the trips (by purpose and by mode) during each hour and for each direction, production-to-attraction or attraction-to-production; Directional split factors are also required • This approach can significantly increase model application time	• An advantage of this method is that differences in travel characteristics by time of day can be considered in trip distribution and mode choice • Procedure is not sensitive to increasing levels of congestion, nor is it sensitive to policy changes or congestion-management actions

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This approach is neither link-specific nor trip-specific; because it was designed to model the travel impacts of ITS deployment, it assumed that a significant amount of travel information was available to travelers and thus the traveler's temporal response to

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1.0 Introduction

In recent years, there has been increasing interest in the ability of travel demand models to estimate travel not only for the average weekday, but for different periods within the day. In the past, travel demand models were mainly used for such purposes as determining the size or capacity of major new transportation investments or estimating travel demand and revenues for transportation projects such as new transit lines. Nowadays, models are required to be analysis tools for a much broader range of issues and transportation policy and project alternatives, including transportation demand management (TDM) policies, transportation systems management projects, and air quality analysis. These issues often require much more detailed analysis than in the large scale models of the past, not only spatially, but temporally as well.

This report provides documentation on methods used in U.S. urban areas to handle the issue of time-of-day in their travel demand models. Commonly used practices are described, and the most innovative methods used by metropolitan planning organizations and states are documented in detail. A range of time-of-day related issues are addressed, including disaggregation of daily travel estimates, peak spreading, and emerging approaches. The "Terminology" section of this report (Section 6.0) lists acronyms and technical terms with their definitions.

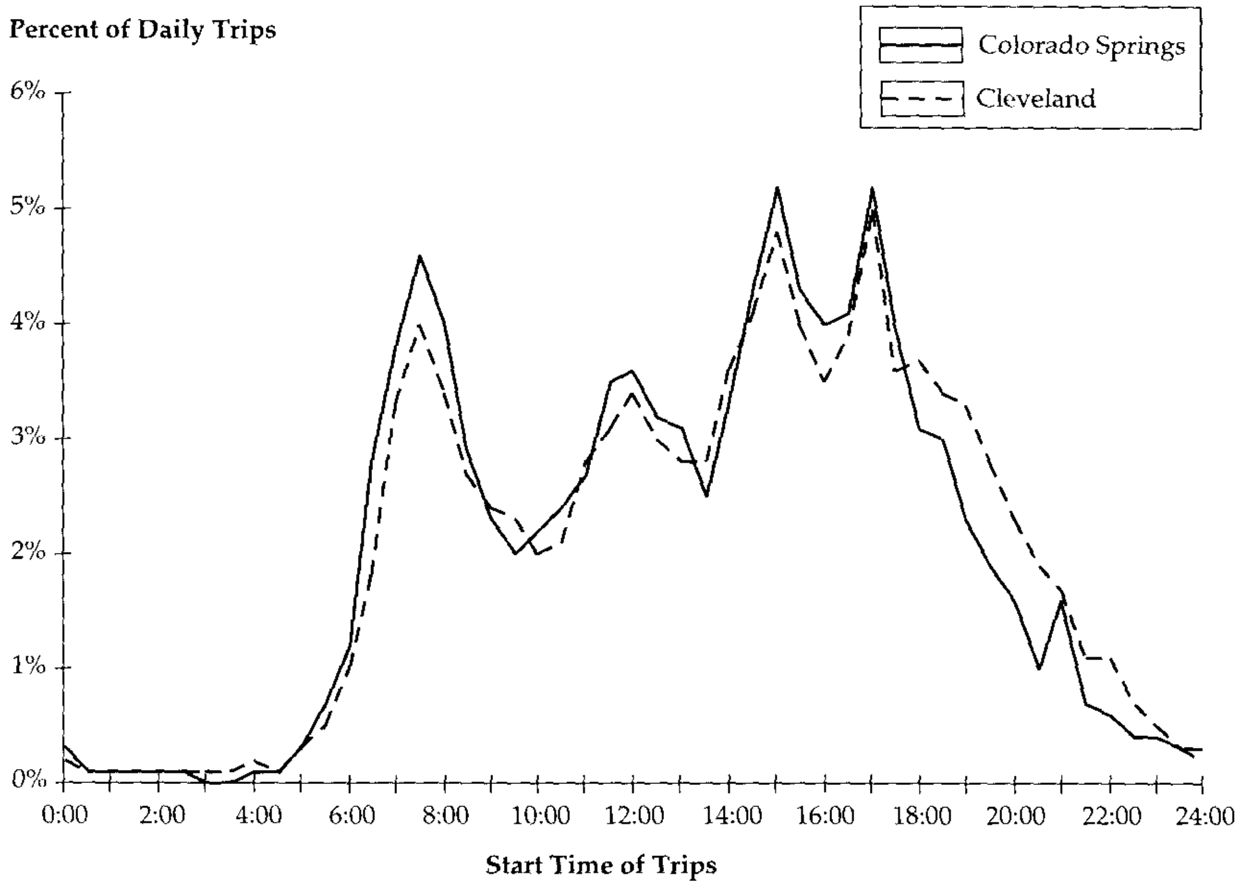
1.1 Background

In travel modeling, the simplest form of trip assignment is to assign a single peak period or daily vehicle trip table to the highway network. In the past, this procedure has provided adequate information for the development of long-range transportation plans, identification of required new facilities, and planning for major investments in alternative modes of travel.

These traditional uses of travel data from daily assignments are still valid objectives of travel demand modeling and work reasonably well for general planning purposes, especially if there is relatively little congestion in the planning region. However, increasing traffic congestion together with recent environmental and economic considerations have resulted in increased emphasis on the management of traffic systems and the development of capabilities to forecast congestion levels throughout the day.

All regions experience some peaking of travel demand in the use of the transportation system. As an example of this, Figure 1.1 shows the percent of daily trips by start time based on two household travel surveys in Colorado Springs, Colorado and Cleveland, Ohio. These two metropolitan areas are quite different in size, transportation system, and economic activity. While these cities are quite different in character, they exhibit

Figure 1.1 Percent of Trips by Time of Day



strikingly similar patterns in tripmaking by time-of-day. Both cities are characterized by the morning peak period and the afternoon peak "plateau," along with a noon-time "mini-peak." While the total magnitude of trip making and transportation supply is substantially different for the two cities, both cities are similar in that they would strain the transportation systems during the peak periods.

The time at which travel occurs and, more specifically, travel peaking intensity and duration are critical to the estimation of a number of important travel performance measures, including speeds, congestion, and emissions. Yet peaking and time of travel are included in the traditional travel model in highly approximate ways, typically by developing peaking or time-of-day factors from observed data and assuming the same patterns will persist in the future. More robust, behavioral representations of the time-of-day of travel have only been recently introduced into the travel demand modeling practice, especially in large urban areas with significant levels of traffic congestion.

1.2 Need for Time-of-Day Modeling Procedures

During the past two decades, there has been a changing emphasis in transportation planning, resulting in travel demand models needing the capability of analyzing travel conditions at different times of day. A major focus is now being placed on traffic congestion and air quality issues as related to transportation planning. Typically, the transportation planner is asked to identify highway system deficiencies, develop plans for traffic management, and estimate traffic growth and air quality impacts related to new developments. Some of the emerging requirements are summarized below:

- Vehicle Emissions and Air Quality Analysis. The Federal Clean Air Act Amendments (CAAA) and State Clean Air Acts have established stringent air quality analysis standards. Analysis of vehicle emissions depends on several inputs from travel demand models including traffic volumes, vehicle speeds, traffic compositions, vehicle-miles and hours of travel by facility type, by vehicle type, by hour of the day, and by vehicle starting mode (hot starts and cold starts). Furthermore, accurate forecasts of vehicle volumes and speeds by time-of-day are required due to the wide variation of emissions levels as vehicle speeds change.

- Congestion Management Programs. The Intermodal Surface Transportation Efficiency Act (ISTEA), and State Congestion Management Programs have also established stringent analytical standards. These requirements have created many specific analysis needs to be addressed using travel demand models including the ability to accurately forecast travel speed, congestion, delay, and time-of-day travel. As traffic management strategies on existing transportation facilities replace capital improvements that increase capacity, travel demand models must capture the effect that these traffic management strategies have on time-of-day travel.

- Identification of Highway System Problems. Many roadway problems stem from peak period congestion. In many urban areas, simply factoring daily volumes to a single peak hour is not sufficient to accurately quantify peak travel demands, since the severity of the peaking and the congestion vary throughout the urban area and over time. As travel demand increases and exceeds the transportation supply, failing to account for route diversions caused by congestion results in a false picture of the highway system.

- Transit Analysis. While travel demand models for large urban areas have long had transit analysis capabilities, they have generally been rather imprecise tools to measure the amount of transit travel. Mode choice models generally are applied at the daily level (or to daily trips by purpose), meaning the variations in transit service availability throughout the day are ignored. Transit assignments are usually all-or-nothing assignments of a daily transit trip table with time-of-day factors sometimes applied at the link level. This severely limits the capability of travel demand models to forecast transit patronage, especially in cases where transit ridership may be changing significantly, for alternatives that may significantly alter transit usage trends, or for alternatives that significantly change the ratio of base to peak period supply.

- Analysis of Transportation Demand Management (TDM) Alternatives. In many areas, TDM alternatives are being considered as ways to alleviate peak traffic congestion, reduce dependence on single-occupant auto travel, and address air quality and other environmental concerns associated with auto travel. Often these measures are aimed at peak period travelers, especially home-to-work commuters. Types of TDM policies that require peak travel analysis capabilities include parking charges, congestion pricing, transit subsidies, variable work hours, and telecommuting.

- Time-of-Day Travel Choices. As peak period congestion increases, many travelers wishing to avoid the added delay have some choice when it comes to the time they choose to make trips. This is evidenced by "peak spreading" that is occurring in many urban areas. As congestion increases, it can be expected that more travelers will choose to move departure times away from peak periods. The ability to model this type of behavior is critical when analyzing alternatives that may significantly change the times and costs of traveling during peak periods.

- Analysis of Intelligent Transportation Systems (ITS). ITS is currently under deployment in many urban areas as a lower-cost alternative to capital improvements. ITS includes advanced traffic management systems, advanced traveler information systems, commercial vehicle operations, and advanced public transportation systems. Analysis of ITS systems requires improved modeling capabilities to accurately estimate changes in operational characteristics such as traffic volumes, speed, delay, and queuing by time-of-day.

2.0 Standard Approaches

The purpose of time-of-day travel demand models is to produce traffic assignment results that more accurately reflect the capacity restraining impact of the highway network on traffic volumes and speeds. In highly congested areas, particularly large urban areas, the finite amount of physical highway capacity results in the spreading of the peak periods. While it is not possible for a roadway to carry an hourly volume of traffic that is greater than its theoretical maximum capacity, the highway assignment algorithms commonly used can produce traffic volumes on roadways that exceed the capacity. In these cases, the volume of traffic assigned during the peak periods must be constrained and change as the capacity of the highway system is reached. This can be done by using a simulation-based or dynamic assignment procedure or by increasing the time period over which the volume can be assigned. Several methods have been developed that account for this spreading out of the peak volumes.

In most smaller to medium-sized urban areas the peak periods have not spread to the same extent as those in the larger areas. In these areas, while there are capacity restraints at some localized points in the highway system, the overall highway system has not reached capacity during the peak period, and traditional assignment procedures can adequately reflect highway capacity. Rather than shifting to another time period, the vehicles shift to alternative routes that are uncongested. For these smaller to medium-sized areas (and even for some large areas), historically the method for obtaining daily capacity restrained traffic assignments has been to multiply the hourly capacity by a constant factor, say 10, to reflect the "daily" highway capacity. This is based on the assumption that the peak hour traffic represents about 10 percent of the daily volumes.

Most microcomputer transportation demand modeling software programs contain parameters which are used to adjust for daily capacity constrained assignments. There are several problems with this simplistic approach:

- This type of factoring does not account for the differences in peaking characteristics among different locations in the network; and

- The directional imbalance of traffic volumes during the a.m. and p.m. peak periods is not considered.

Trips occur at different rates at different times of the day. Typically, there are one or more peaks in daily travel. The dominant weekday peak periods are in the morning (a.m. peak period) and in the late afternoon (p.m. peak period). A peak period can be characterized by its maximum trip rate (in trips per unit time). The peak hour is the hour during which the maximum traffic occurs. The portions of the peak before and after the peak hour are called the "shoulders of the peak."

The choice of which peak period(s) to model must be made taking in account such considerations as the availability of count data, previous modeling efforts, local conditions, and the applications for which the model is intended. Air quality problems may point to a need for information about a particular peak period. For example, the a.m. peak is most critical for ozone purposes, since morning emissions of volatile organic compounds (VOC) and nitrous oxide (NOx) have a longer time to react to light than do pollutants emitted in the p.m. peak. As a result, ozone (O3) concentrations typically peak during the late-morning or early-afternoon hours. On the other hand, areawide traffic volumes and congestion are typically higher during the afternoon peak than at other times of day; CO concentrations are also typically higher in the afternoon and evening hours. Hence an area with a CO problem may need to devote modeling resources to the p.m. peak.

The length of peak periods to be represented in the models also must be decided. While it is common to specify a one-hour peak period, many metropolitan areas have some facilities experiencing congestion for several hours a day, and so have defined peak periods that are at least two or three hours long. Network capacities are defined for the entire peak period, effectively allowing for "peak spreading" within the peak period. An implicit modeling assumption here is that most trips can be completed within the peak period.

The time-of-day factor (TODF) is the ratio of vehicle trips made in a peak period (or peak hour) to vehicle trips in some given base period, usually a day. Time-of-day factors are most commonly specified as exogenous values that are fixed and independent of congestion levels. If applied prior to trip assignment these time-of-day factors are usually determined from household activity/travel survey data and from transit on-board and auto intercept surveys, with a separate TODF for each trip purpose. If applied after assignment, the peaks' timing and duration are generally estimated from traffic data (e.g., 24-hour machine counts on streets and highways, transit counts, or truck counts), perhaps interpreted and adjusted based on data from special studies (e.g., travel surveys of workplaces and customer-serving businesses in a particular area or driveway counts at major activity centers). Occasionally, time-of-day factors are borrowed from other areas and adjusted during the model calibration process. However, this practice has severe limitations because TODFs are highly dependent on each area's characteristics such as facility design and capacity, types of employment, and local custom and business practices.

Peaking also has been estimated by extrapolation from work trip data, in applications that model only work trip models. In these cases, the peak period work trip table is expanded to represent trips for all purposes during the peak period (or for the entire day), with the expansion factors derived from full runs of the regional model system (if a subarea application), from survey data, or even from national sources. Although this approach is fairly common in subregional planning and design applications, it is not a substitute for having and using a complete set of work and non-work travel demand models, and is not recommended as the primary means of conducting major transportation analyses.

There are several commonly employed methods for accounting for time-of-day of travel in the four-step process. To proceed from the initial daily trip generation estimates to the volume estimates by time period, average daily travel estimates must be converted to trips by time period. This can happen at four places in the modeling process:

- After trip assignment;
- Between mode choice and trip assignment;
- Between trip distribution and mode choice; and
- Between trip generation and trip distribution.

2.1 Time-of-Day Modeling After Trip Assignment

Description

In this method, the assigned daily link volumes are factored to produce volume estimates by time-of-day. This method is the simplest and probably the most commonly used. The post-assignment static technique uses a daily traffic assignment as a basis. In its simplest form, peak hour factors (usually in the range of 8 to 12 percent) are used to reflect peak period link-level travel demand.

Figure 2.1 describes the process of time-of-day modeling after trip assignment. The daily assigned volumes are multiplied by the peak period factor to estimate peak period demands. The technique can be refined to reflect different peak period percentages as shown in Table 2.1. Link capacities should also be varied by area type and facility type to ensure consistency between the "supply" represented to the assignment and the final volume estimates. A directional split percentage (e.g., 60 percent), derived from observed traffic conditions, is applied to obtain link-level peak volumes.

Applicability and Limitations

This procedure does not allow consideration of time-of-day related level of service characteristics in the travel demand models. In addition, equilibrium assignment on a daily basis is much less meaningful than assignment for shorter, more homogeneous periods where concepts such as capacity have more meaning.

This procedure yields only a rough approximation of link- or corridor-level peaking, though it may suffice for smaller MPOs where the duration and intensity of congestion are limited. In general, there is little reason to expect specific facilities to exhibit the same peaking patterns or characteristics as "regional averages," and application of a fixed TODF may be a significant source of error.

This post-assignment TOD factoring technique is useful for smaller urbanized areas where the peak periods have not spread to the extent of those in larger urban areas. However, this technique is a static approach that does not account for localized effects of changes in demand, nor does it fully account for the impacts of assigned traffic volumes exceeding capacities on links. The impact of the localized effects can be demonstrated by

Figure 2.1 Time-of-Day Modeling After Trip Assignment

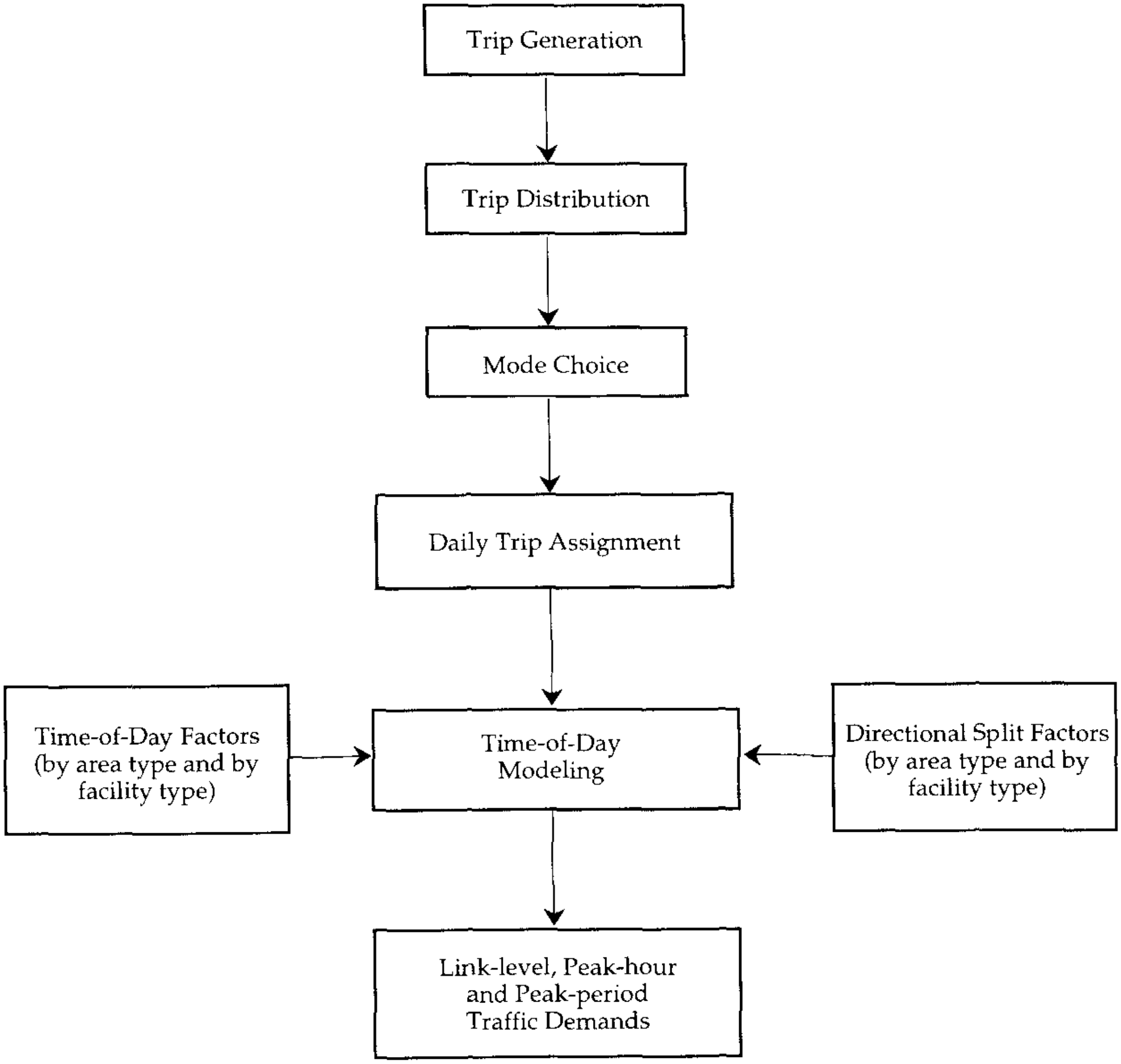


Table 2.1 Post-Assignment Static Technique - Peak Hour Percentages

	Area Type				
	CBD	Central City		Suburban	
Facility Type	**All Orientations**	**Radial**	**Crosstown**	**Radial**	**Crosstown**
Freeways/Expressways	9.5	9.0	8.5	9.0	10.0
Arterials	9.5	9.0	9.0	9.5	8.5
Collectors	10.5	10.5	10.5	9.5	9.5

Source: NCHRP-187.

the following example. Suppose a suburban cross-town arterial is bounded by vacant land in a base-year assignment. If the factors presented in Table 2.1 are used, 8.5 percent of the daily volume would occur in the peak period. However, suppose that the vacant land is developed into a major suburban office park in the future. In such a case, it is likely that the future peak hour percentage for the arterial in the proximity of the office park would be greater than 8.5 percent. The post-assignment static technique would not reflect this change.

Another limitation is a lack of consistency in the modeling process. Trip generation, trip distribution, and mode choice are performed using daily trips. Some "consistency" can be provided by performing trip distribution and mode choice for home-based work trips using peak period travel impedances, with off-peak period impedances used for other trip purposes.

2.2 Time-of-Day Modeling between Mode Choice and Trip Assignment

Description

A second procedure for accounting for time-of-day travel is time-of-day modeling between mode choice and trip assignment, or diurnal-direction split factoring. This widely used procedure factors the purpose-and mode-specific daily trip tables produced by the mode choice model. These trip tables are then used as inputs to time period-specific trip assignments. For example, three time periods may be used: morning peak, afternoon peak, and off-peak. Peak hours, rather than peak periods, are modeled in some regions. Daily traffic volumes are produced by adding up the results of the morning, afternoon, and off-peak period traffic assignments. An example of this procedure is shown in Figure 2.2 and in Tables 2.2 and 2.3 for auto and transit trips, respectively.

Directional splits (e.g., home to work (HTW) vs. work to home (WTH) must be determined as part of this process. If peak period to peak hour conversions are also done at this point, some level of service or trip characteristics can be considered in the development of factors. For example, trip length and congested travel time can be a consideration in determining whether peak period auto trips occur during the peak hour.

The process for preparing peak hour directional trip tables requires the factoring of the person or vehicle production-attraction formatted trip tables to peak hour (or period) origin-destination formatted vehicle trip tables. The data required include an hourly distribution of trips across the day. These should be by trip purpose, usually grouped into home-based work, home-based non-work, and non-home-based. From this diurnal distribution of trips, factors are developed which represent the percentages of the trips (by purpose) during each hour and for each direction, production-to-attraction or attraction-to-production. The hourly distribution is developed from local travel survey data. The production-attraction formatted trip tables are multiplied by the appropriate factors and transposed where necessary to produce balanced origin-destination trip tables.

Figure 2.2 Time-of-Day Modeling Between Mode Choice and Trip Assignment

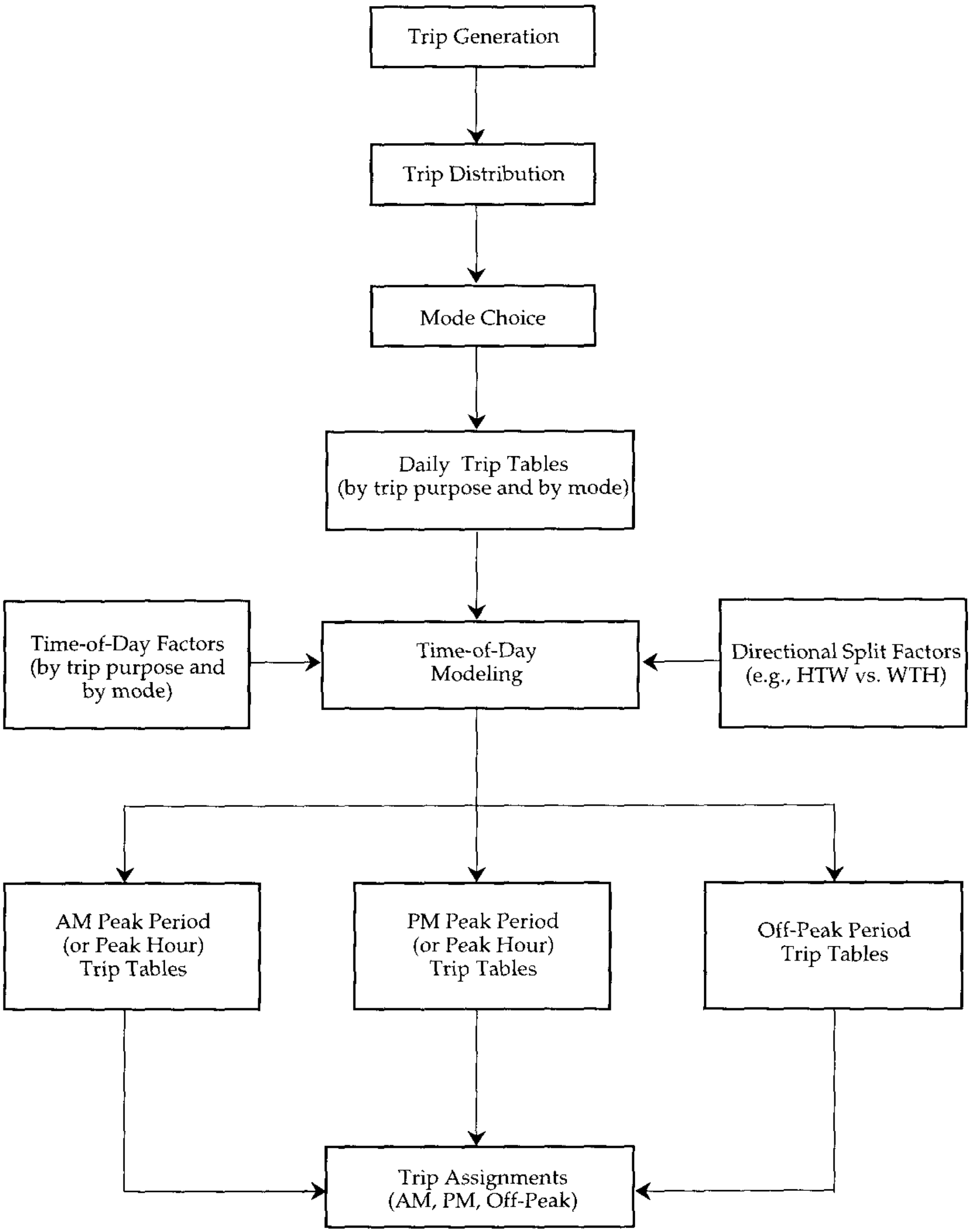


Table 2.2 Post-Mode Choice Auto Time-of-Day Factors

Purpose	AM 2 HR 7:00-9:00	AM PK 7:15-8:15	PM 2 HR 3:30-5:30	PM PK 4:30-5:30	MIDDAY 2:00-3:00
HBW	25.7	15.5	24.1	14.48	3.53
P-A	25.1	15.2	2.1	1.10	1.44
A-P	.6	.28	21.98	13.38	2.09
HBO	6.93	3.2	16.08	8.25	6.85
P-A	5.12	2.48	6.22	3.20	3.23
A-P	1.8	.72	9.86	5.05	3.62
NHBW	11.65	6.81	24.26	12.86	7.97
P-A	2.37	.77	22.86	12.28	6.09
A-P	9.27	6.04	1.4	0.58	1.88
NHBNW	4.19	2.02	15.29	6.89	10.22
HBS	42.82	35.86	5.04	1.89	23.27
P-A	42.82	35.86	0	0	0
A-P	0	0	5.04	1.89	23.27
HBC	25.01	16.67	11.46	5.5	9.38
P-A	24.25	16.07	2.97	1.78	1.64
A-P	.75	.60	8.49	3.72	7.74

Source: "The Phase III Travel Demand Modeling Forecasting Model: A Summary of Inputs, Algorithms, and Coefficients," Portland METRO, June 1, 1994.

Table 2.3 Post-Mode Choice Transit Time-of-Day Factors

Purpose	AM 2 HR 7:00-9:00	AM PK 7:15-8:15	PM 2 HR 3:30-5:30	PM PK 4:30-5:30
HBW	32.08	15.46	30.63	21.53
P-A	31.79	15.31	1.01	.43
A-P	.28	.14	29.62	21.09
HBO	1.35	.54	14.4	6.79
P-A	1.35	.54	5.4	2.44
A-P	0	0	8.96	4.34
NHBW	8.69	2.89	21.74	11.59
P-A	1.74	.77	20.48	11.20
A-P	6.95	2.12	1.26	.39
NHBNW	0	0	22.07	7.7
HBS	43.65	26.90	12.7	3.05
P-A	43.65	26.90	0	0
A-P	0	0	12.7	3.05
HBC	32.51	18.4	11.05	4.92
P-A	31.53	17.66	2.87	1.58
A-P	.98	.74	8.17	3.34

The diurnal factors are best derived from household travel survey data. Person-trips by time-of-day and by trip purpose are required for diurnal factor derivation. Also, a good estimate of auto occupancy rates by purpose and time-of-day is also required. If the region is using a mode choice model to produce the auto vehicle trips then the model results should be compared with observed auto occupancy rates.

Strengths

The diurnal-direction split factors can be derived from household travel survey data for internal person trips, commercial vehicle surveys for truck trips, and external station surveys for internal-external and external-external trips. This procedure is an improvement over the TOD modeling after trip assignment since it explicitly takes into account different peaking characteristics of trips made for different trip purposes and results in trip tables for assignment that are more consistent with the state-of-the-practice equilibrium traffic assignment process generally employed in the travel-forecasting process.

A procedure that is widely used is to factor the daily trip tables by purpose and produce peak hour (or peak period) directional origin-destination trip tables. These trip tables are static and are not dynamically adjusted during the assignment process. The daily volumes are produced by adding up the results of the a.m., p.m., and off-peak traffic assignments. An added benefit of using this technique is that assignments by time-of-day can be produced for input to air-quality analysis and for the better estimation of congested speeds for use in the trip distribution and mode choice models.

This method allows modal considerations to be part of the time-of-day choice process. For example, transit trips can be more concentrated within peak periods than auto trips. However, it also means that mode choice must be modeled on a daily basis, with no differences in inputs to reflect peak congestion or levels of transit service.

Applicability and Limitations

While this procedure represents an improvement over TOD modeling after trip assignment techniques, there are limitations:

- First, the process is typically a static process. The diurnal-direction split factors are commonly fixed using base-year survey data and, as a result, are independent of future congestion levels. This approach assumes that the entire trip is completed within the assignment hour (or the assignment period), even though the actual duration of the trip may extend beyond the assignment period. This situation is exacerbated in future forecasts when the travel demand and congestion increase, yet the same percentages of daily trips are presumed to be accommodated in the peak period or peak hour. Because this approach results in trip distribution and mode choice being done without accounting for congested times, it is highly undesirable in all but the least congested areas. However, if feedback is used between mode choice and trip assignment this procedure could account for congested travel times although the mode choice model is run for daily travel.

- The second limitation is a lack of sensitivity to general policy changes and increasing congestion levels. Since traveler choice of time-of-day is not modeled, the procedure is insensitive to travel demand management strategies such as congestion pricing and implementation of variable work hours. This procedure is also non-responsive to corridor or subarea-specific changes. Thus, corridor-specific congestion problems and congestion reduction efforts of transportation management areas cannot be analyzed using this procedure. For example, future time-of-day factors and directional split factors would not remain constant, but would change based on the emergence of congestion pricing and/or corridor traffic management improvements.

- The third limitation is a lack of consistency in the modeling process. Trip generation, trip distribution, and mode choice are performed using daily trips. Some "consistency" can be provided by performing trip distribution and mode choice for home-based work trips using peak period travel impedances, with off-peak period impedances used for other trip purposes. However, as can be seen in Table 2.2, a large percentage of home-based work trips take place in the off-peak period, and large percentages of non-work trips take place in the peak periods.

Many of the adjustments being made to trip tables are intended to better cope with modal, facility, corridor, and subregional variations in peaking. Recently, some agencies have developed ad hoc procedures which draw upon empirical studies to estimate the probable impact of congestion on peaking levels and duration. While it can be argued that these adjustments serve to improve the realism of assigned traffic volumes, they generally fall short of being formal models (e.g., relating the peak hour percent to the ratio of actual daily volume to theoretical daily capacity in a corridor). Moreover, adjustments are almost always applied to reduce unrealistically high volumes in excess of capacity; peak loads rarely are adjusted upward in forecasting applications to reflect higher future flows.

2.3 Time-of-Day Modeling between Trip Distribution and Mode Choice

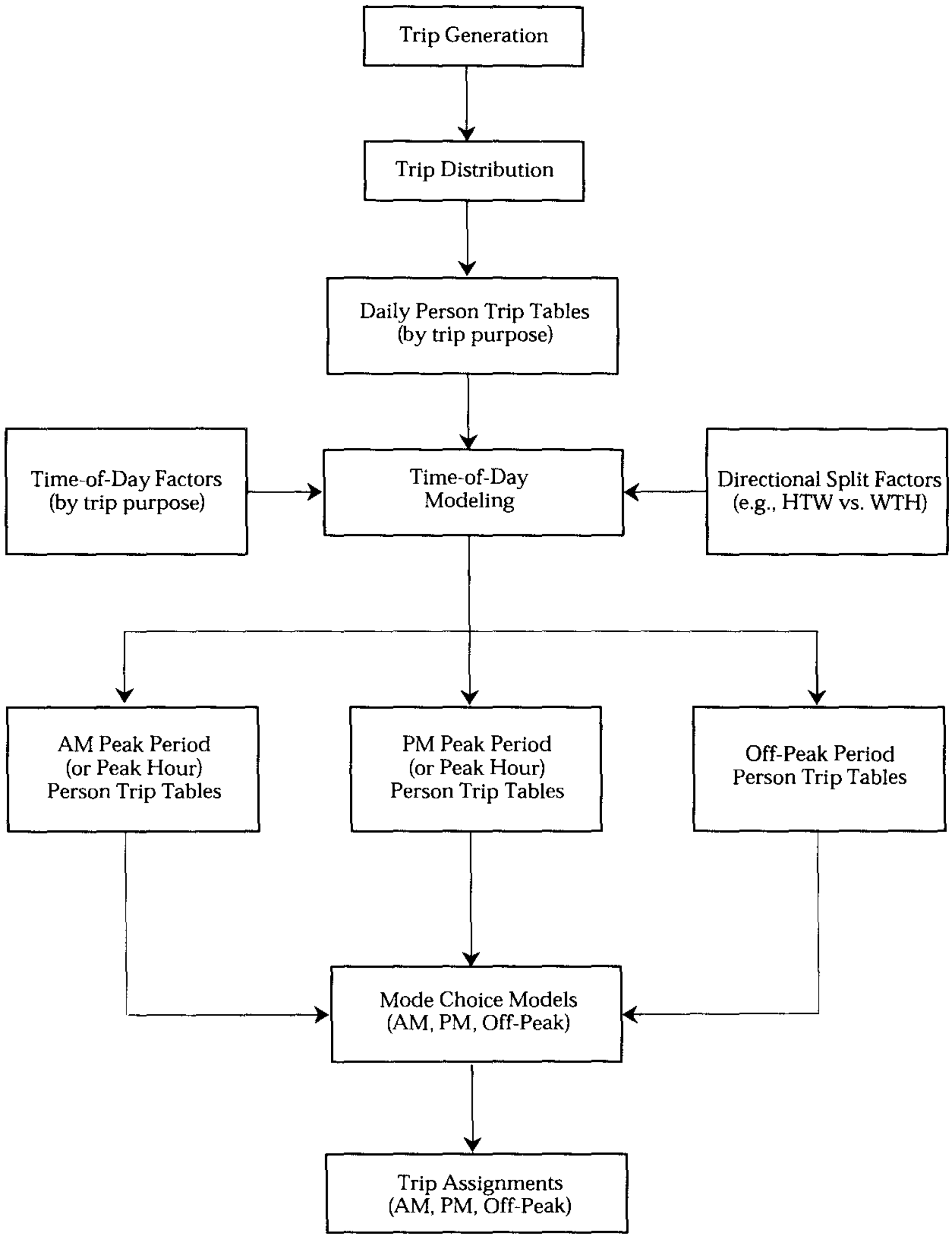
Description

In this method, the total daily person trip tables by purpose are divided into total person trip tables by purpose for each time period. These estimates are then used as inputs to time period specific mode choice models. Directional splits (e.g., home to work vs. work to home) must be determined as part of this process. This procedure is shown in Figure 2.3. If peak period to peak hour conversions are also done at this point, a second set of factors is used.

Applicability and Limitations

This procedure appears to be a slight improvement on the pre-distribution procedure described in Section 2.4. Only a single trip distribution model is needed for each trip

Figure 2.3 Time-of-Day Modeling Between Trip Distribution and Mode Choice



purpose, and, although time-of-day-specific congestion is not considered in trip distribution, peak period travel times and transit service levels are considered in mode choice. However, the effects of time-of-day characteristics such as congestion or transit levels of service are still ignored in the way trips are allocated to time periods.

Another limitation is a lack of consistency in the modeling process. Trip generation and trip distribution are performed using daily trips. It is recommended that some "consistency" is provided by performing trip distribution for home-based work trips using peak period travel impedances, with off-peak period impedances used for other trip purposes.

An example of a time-of-day model application between trip distribution and mode choice is the preliminary New Hampshire statewide travel model system. While this model system is tour-based and therefore does not have the four traditional model steps, the time-of-day factors are applied prior to mode choice. Tables 2.2 and 2.3 are examples of the factors used to allocate daily trips by purpose into trips for four different time periods. These factors are applied through macros in the travel modeling software. The inputs are traditional daily production-attraction trip tables by purpose, and the outputs are origin-destination tables by purpose for each time period.

■ 2.4 Time-of-Day Modeling between Trip Generation and Trip Distribution

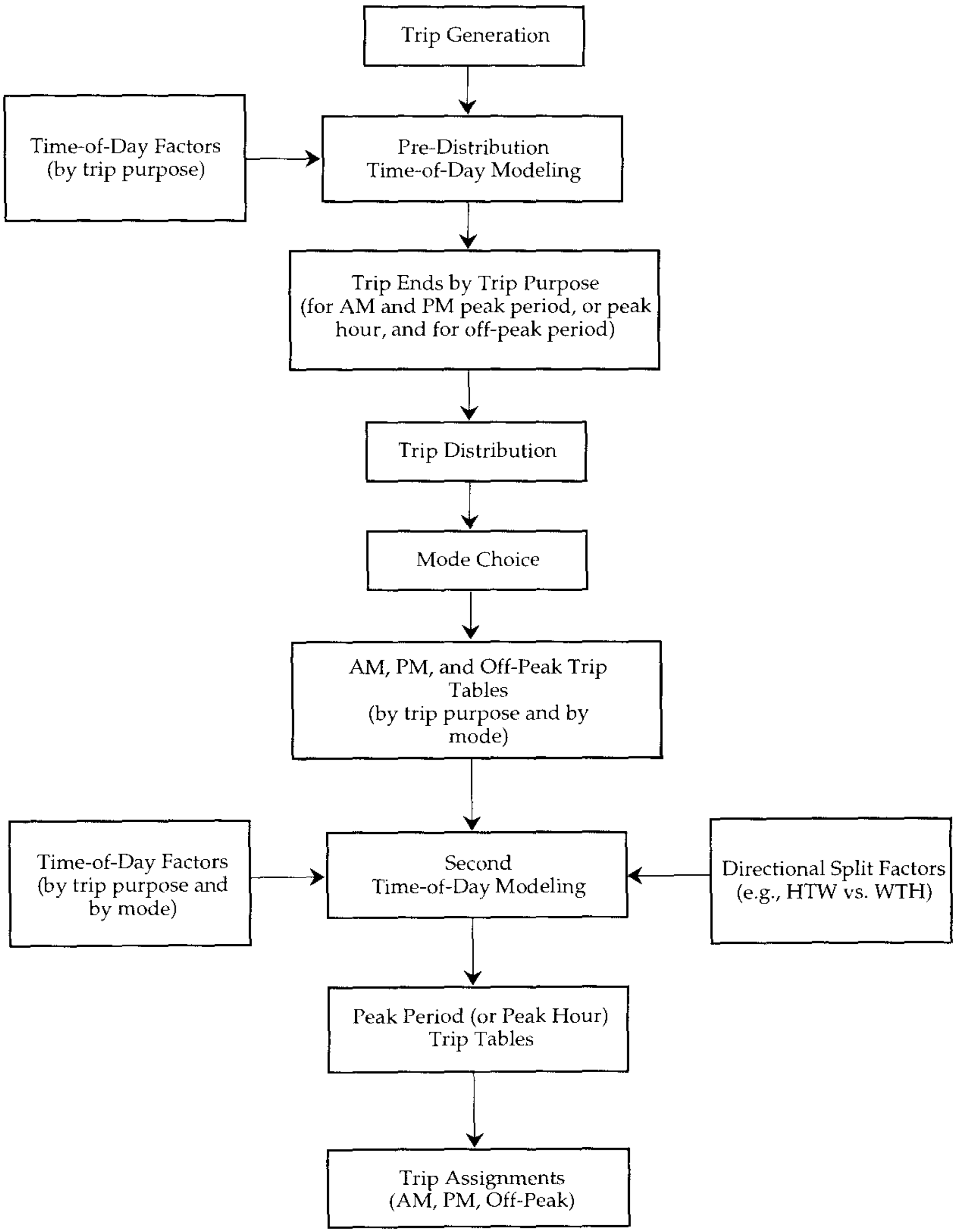
Description

This process factors the daily trip productions and attractions by purpose and zone to produce trip end estimates by purpose and zone for each time period. These estimates are then used as inputs to time period specific trip distribution and mode choice models. Directional splits (e.g., home to work vs. work to home) must be determined as part of this process. If peak period to peak hour conversions are also done at this point, a second set of factors is used.

Many travel demand models use peak period level-of-service characteristics (travel times and costs) for trip distribution and mode choice analysis of home-based work trips and off-peak characteristics for non-work trips. However, there are trips of all purposes during each of these periods. In models developed for the Metropolitan Transportation Authority's Red Line East Side Extension project in Los Angeles, a pre-trip distribution time-of-day model was developed. In this technique, the trip ends are split by time period for each trip purpose. The same technique was applied in the model developed for the Dulles corridor alternatives study.

The time-of-day approach used in these applications is a two-step process as shown in Figure 2.4. The initial step is the pre-trip distribution model, in which a set of factors is used to calculate trips by time-of-day, usually for multi-hour peak and off-peak periods, and by trip purpose. The factors are based on peaking characteristics such as trip purpose, jurisdiction, area type, and socioeconomic stratification. These factors are applied to

Figure 2.4 Time-of-Day Modeling Between Trip Generation and Trip Distribution



the trip ends from the trip generation model and produce trip ends by peak and off-peak periods for each of the trip purposes.

The peak and off-peak trip ends are then used in the trip distribution and mode choice models. The resulting trip tables, by mode and time-of-day, are then factored in the second, or final, time-of-day model. The user can specify the time period desired and factors based on trip purposes and mode are applied to produce the desired trip tables, usually representing peak and off-peak hours rather than multi-hour periods. Secondary factors which may be input to the model include length and location of the trip.

In some applications of this approach, peak network characteristics (e.g., travel times) are used for work mode choice, and off-peak characteristics are used for non-work mode choice. In other applications, each trip table (by purpose) is split among time periods, so that mode choice and assignment can apply to the range of conditions experienced by travelers. Both approaches impose strong assumptions about travel behavior. Federal Transit Administration (FTA) has indicated its preference for the first approach, primarily out of concern about the stability of the unspecified factors leading to the time splits in the latter: "The first approach is preferred because the time-of-day factoring is done (by purpose) for trips on all modes together, reflecting only the influence of activity patterns throughout the day. These factors are likely to be reasonably stable over time and across alternatives." (UMTA, 1986)

Strengths and Limitations

Peak/off-peak factors may be developed as an integral part of the trip generation phase. In this technique, models may directly include a measure of congestion (or more generally, a measure of accessibility) in estimating trip generation rates at particular locations and times of day. This approach has the advantage of allowing for a correlation between the number of trips made and the qualities of transportation services available at specific times and locations.

Another adjustment that can be made to the traditional post-mode choice application of diurnal direction split factors is to apply the diurnal factors prior to trip distribution, model trip distribution and mode choice by time-of-day, and convert the resulting production-attraction trip tables resulting from the mode choice model to origin-destination trip tables prior to assignment. This approach starts to address the consistency problem noted for the post-mode choice application of diurnal-direction split factors. However, it can significantly increase model application time since the number of trip distribution and mode choice model applications will be, at least, doubled. Also, this approach requires application of separate mode choice models for peak and non-peak periods.

The major advantage of this method is that differences in travel characteristics by time-of-day can be considered in trip distribution and mode choice. For example, peak period travel times can be used in trip distribution and mode choice models applied to peak period trips. However, this also means that a larger number of distribution and mode choice models must be estimated, one for each trip purpose-time period combination. Assuming five trip purposes and four time periods, this could mean up to twenty trip distribution and mode choice models.

While the pre-distribution time-of-day modeling approach increases the consistency of the modeling process, it does not address any of the other deficiencies noted with existing practices. Specifically, the procedure is not sensitive to increasing levels of congestion, nor is it sensitive to policy changes or congestion-management actions. The effects of time-of-day characteristics such as congestion or transit levels of service are ignored in the way trips are allocated to time periods. In most cases, the peaking factors are derived from the most recent travel survey, but specific adjustments are made with a heavy dose of judgment. FTA cautioned against this approach, noting that the factors may not be stable over major changes in the "[transportation] system that affect the quality of service for work trips differently from the quality for non-work travel." (UMTA, 1986)

3.0 Innovative Approaches

As peak hour congestion increases on urban highways, drivers wishing to avoid the added delay have a number of options, including:

- Seek alternative routes to bypass the congestion;
- Switch from auto to transit (or to another mode);
- Choose a different, more accessible, destination;
- Stop making the trip; or
- Make the trip at a different time-of-day.

Existing travel demand models can predict the extent to which some of these options (rerouting, mode shifts, destination shifts) will be chosen, but not the complete set of possible responses. Several methodologies are available for assessing the travelers' temporal responses to congestion. This section describes innovative methods used by MPOs or state agencies that go beyond the relatively simple factoring methods described in the previous section.

Three approaches to improving the time-of-day modeling process are addressed in this section. These "Peak Spreading" methodologies work within the confines of the current "four-step" modeling process. The peak spreading process addresses the problem that projected demand exceeds capacity in certain corridors during the peak period and that failing to account for the excess demand results in a flawed assessment of travel conditions in the future. The three general approaches to implementing peak spreading analysis discussed here include:

- **Link-based peak spreading.** This approach focuses on measures to obtain more realistic traffic assignments. This method has been implemented for a study in the Phoenix area. This approach can be used with any of the traditional TOD factoring procedures described in the previous section.

- **Trip-based peak spreading.** This method focuses on using selective reductions to trip table interchanges for those links that are overassigned. This procedure has been implemented for a subarea model in the San Francisco Bay Area (Tri-valley model), for a study in Boston, Massachusetts (Central Artery/Tunnel Project), and for a study in Washington D.C. This approach requires time period trip tables (i.e., a pre-assignment factoring procedure).

- **System-wide peak spreading.** This method includes a approach that has been implemented by the Volpe National Transportation System Center (VNTSC) within a modeling framework applied in the evaluation of Intelligent Transportation Systems (ITS).

■ 3.1 Link-Based Peak Spreading

Description and Applicability

The effect of traffic congestion on route choice has led to the development of equilibrium-based traffic assignment techniques. However, as congestion levels have increased, the limitations of the equilibrium traffic assignments based on static, regional diurnal factoring of trip tables has also become apparent, and revised approaches for time-of-day modeling have attempted to improve the modeling process. One such approach is to account for congestion at the link level and divert trips to the "shoulder" hours on either side of the peak.

Experience with urban traffic suggests that peaking is sensitive to congestion. One of the most well known examples of a peak spreading method was developed for Phoenix, Arizona (Loudon et al, 1988). The objective of this method was to provide an estimate of the net effect of traffic congestion without identifying the magnitude of each type of behavioral response. The result was a set of significantly more realistic estimates of future traffic volumes and speeds on congested highways, as well as more realistic estimates of regional measures such as vehicle-miles of travel (VMT).

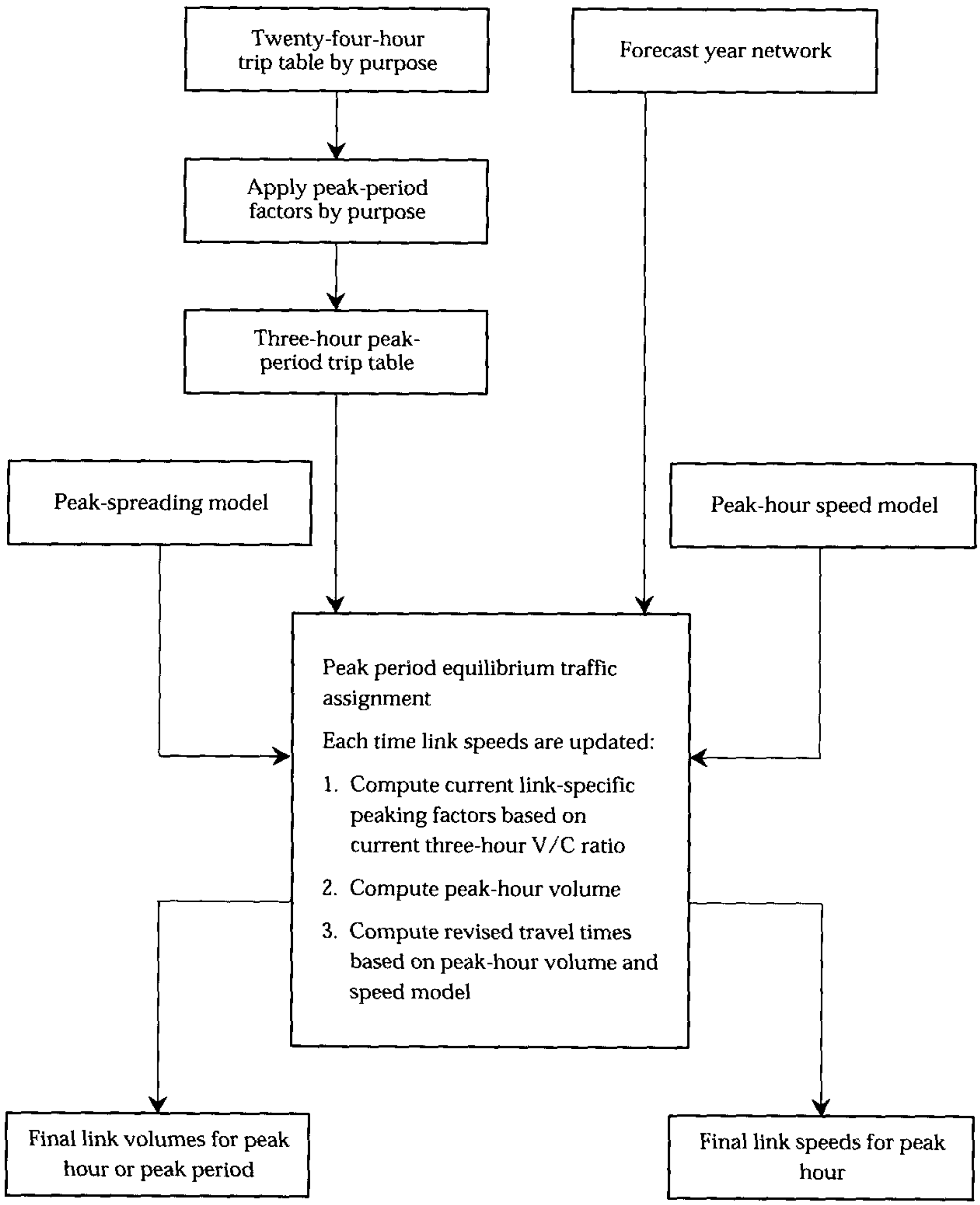
The Phoenix study was based on data collected from 49 corridors in Arizona, California, and Texas. These data provided relationships between peak hour and peak period volume as a function of facility type and volume/capacity ratio in the peak period. The procedure hinges on the assignment of peak period, not peak hour, trips. The Phoenix study was based on a three-hour peak period with the total number of trips within that peak period based on a fixed percentage of total daily trips by trip purpose and direction (to or from home) using split factors developed for the region (these TOD factors are applied between trip generation and trip distribution – see Section 2.4). Typically, in peak period assignments, link-specific, hourly capacities are related to period-specific trips through a peak hour factor. This factor is typically applied at a regional level and, in effect, relates the percent of the period's trips that take place in the most congested one-hour time period.

In the Phoenix study, the peak hour factor was allowed to vary for each link based on link congestion levels as measured by volume/capacity ratios. The modeling process which was implemented in Phoenix is illustrated in Figure 3.1. The first step in the process is to produce separate trip tables for each of the three time periods: a three-hour a.m. peak, a three-hour p.m. peak, and an off-peak which includes all other times. Peak spreading and computation of traffic volumes and speeds were applied to each link each time link speed updating is required using the following steps:

1. Compute the ratio of the current assigned three-hour volume to the three-hour link capacity

2. Apply the peak-spreading model to calculate a peaking factor (the ratio of one-hour volume to three-hour volume);

Figure 3.1 Link-Based Peak Spreading
Phoenix, Arizona Model



The functional form chosen for the peak spreading model was:

$$P = 1/3 + a\,e^{b(V/C)}$$

where:

P = the ratio of peak hour volume to peak period (three-hour) volume,

V/C = the volume/capacity ratio for the three-hour period, and

a, b = model parameters.

3. Determine the revised peak hour volume as the product of the peaking factor and the assigned volume;
4. Compute link-level peak hour volume/capacity ratios;
5. Apply a peak hour speed model to estimate revised link speeds; and
6. Continue this link volume updating process throughout the iterative equilibrium procedure.

The peak spreading procedure was applied as part of a peak period (typically three hours) equilibrium assignment. As each link is considered, in turn, during the equilibrium assignment's travel time updating, peaking factors representing the ratio of peak hour volume to peak period volume are computed using a decreasing function of the link three-hour volume-to-capacity ratio. The peaking factor function was estimated with time series and/or cross-sectional vehicle count data. The peak hour volume corresponding to this peaking function was used to estimate revised travel times during each iteration of the equilibrium assignment procedure.

When applied in the Phoenix area, this technique was found to improve the estimates of average speed and VMT. The root mean squared error (RMSE) of speeds on links was reduced from 56 percent (24-hour trips - no peak spreading) to 46 percent (24-hour trips - 24-hour peak spreading) to 36.6 percent (3-hour trips - 3-hour peak spreading). Also, the percent VMT error declined from 16.4 percent to 3.2 percent as compared to observed VMT estimates computed from regional traffic counts.

Limitations

The study noted that there were some limitations with the procedure:

- First, there is no guarantee of continuity of flow in the peak hour prediction. Differences in the three-hour V/C ratio predicted for two adjacent links could result in a different amount of peak-spreading predicted for each. While this could and does occur, the impact of it is likely to be small because of the calibration of the peaking model on a facility type (rather than link-specific) basis, thereby averaging the effects over a facility.

- A second limitation is that the peak-spreading model is applied at the link level while the peak-spreading on a specific link may occur as a result of a single congestion point on some other link in the network or as a result of the perception of travelers of the average level of congestion in the corridor.

- A final limitation of the recommended procedures for peak-spreading is that they do not reflect spreading of the peak outside of a three-hour period."

■ 3.2 Trip-Based Peak Spreading

In the Phoenix link-based peak spreading approach, an underlying assumption was that all the trips would occur in the three-hour period under consideration, although the percentage of trips occurring in the peak hour within that three-hour timeframe could spread as congestion increased. An alternative to the link-based peak spreading approach is a trip-based approach that spreads the number of trips for an origin-destination interchange that occur in the peak period or peak hour.

Three examples of the trip-based peak spreading are available from the literature. These include:

- A subarea model in the San Francisco Bay Area (Tri-Valley model);

- A model applied for a study in Boston, Massachusetts (Central Artery/Tunnel project);

- A model applied for a study in Washington D.C.

Tri-Valley Model Peak Spreading

Description

One trip-based peak spreading scheme has been applied for the Tri-Valley Subarea Model in Alameda and Contra Costa Counties, California. For consistency with the regional San Francisco Bay Area model, the Tri-Valley model was designed as a focused subarea model. The region outside of the subarea was included in the model, albeit at a very aggregate level. The Tri-Valley trip-reduction approach recognizes the overall constraint of the future highway network system capacity (by time-of-day) by limiting the assignment of trips to that network based on the overall capacity of the future network at selected gateways.

The Tri-Valley subarea is transected by two major freeways (I-580 and I-680) that define four major gateways for access into, out of, and through the study area. These gateways were identified as the key capacity constraint locations. Without the trip-based peak spreading process, peak hour traffic assignments through the gateways overwhelmed the subarea network leaving little additional capacity for subarea trips. The regional trips resulted in peak hour volume/capacity ratios at the gateways in excess of 1.0.

For reasonableness, peak hour traffic assignments were constrained at the gateways so that the volume/capacity ratios were equal to 1.0 (or slightly higher). An approach to adjust origin-destination (O-D) matrices to better fit observed or estimated link volumes in a network was used. The structure of the Tri-Valley peak spreading methodology is shown in Figure 3.2. The following steps were used for the trip table reduction and assignment process:

1. Peak hour volumes were assigned to the highway network and V/C ratios calculated;

2. For gateways with V/C ratios in excess of 1.0, target volumes were estimated so that the V/C ratio would be 1.0 (or slightly higher);

3. A mathematical approach[1] for adjusting trip tables was used to reduce the interchange volumes on the O-D pairs using the over-assigned gateways;

4. The revised trip table was assigned and the gateway V/C ratios were checked for reasonableness; and

5. The process was repeated if a close match between the assigned and desired link volumes was not obtained for the gateway links.

Limitations

In the link-based peak spreading approach the trips were all assumed to occur within a three-hour timeframe regardless of capacity. In the trip reduction approach there is no explicit treatment of the trips being reduced. This trip table reduction process does not assume that the excess trips on each congested interchange are not made. Rather, it is assumed that these trips cannot be completed in the peak hour (used for planning and design purposes) and, thus, have been forced to travel outside of the peak hour. In addition, the trip reduction approach does not account for changes in traveler behavior due to congestion.

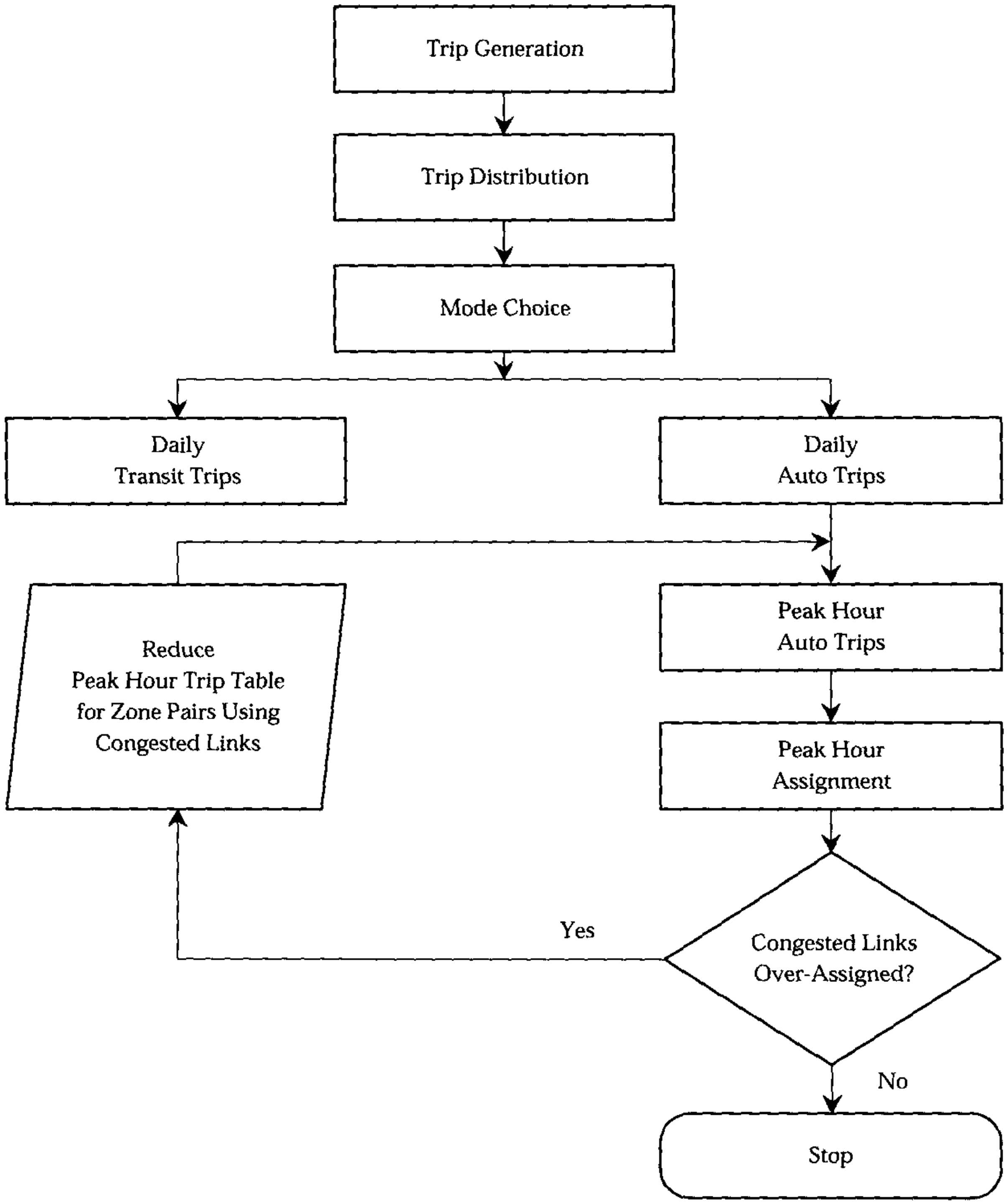
Peak Spreading in the Central Artery/Tunnel Project

Description

When forecast year peak hour vehicle trip tables are assigned to highway networks which are at capacity or congested in the base year, the resulting forecast year traffic volume estimates can exceed capacities by unrealistic amounts. This is because, typically, growth rates are applied during the trip generation phase of the modeling system, without consideration for traffic conditions. Trip distribution models and mode choice models reflect the highway capacity constraints by shortening trip lengths and increasing HOV and transit shares, but the effect of peak spreading (where tripmakers who would previously

[1]INRO Consultants, EMME/2 User's Manual, Software Release 7, May 24, 1994.

Figure 3.2 Trip-Based Peak Spreading



prefer to travel during peak hours make their trips earlier or later to avoid congestion) is not captured in peak hour analyses.

To combat this problem, a technique was developed to reduce a trip table selectively. This technique is described in Rossi et al, 1990. Figure 3.2 shows the structure of this approach. In this procedure, individual origin-destination cells of the trip table were reduced according to congestion levels in the corridor corresponding to the origin-destination pair. This approach was implemented in the Boston area for the Central Artery/Tunnel Project. This was an iterative-factoring procedure applied only to highway trips. In this study, the motivating factor was that base-year peak hour traffic volumes were already at or over capacity throughout downtown Boston. Since daily travel was projected to grow, in the absence of transportation improvements or vehicle travel reduction measures, the use of time-of-day factors based on existing conditions resulted in impossibly high peak hour travel estimates for the future.

The Boston area approach used a trip reduction process that consists of five iterative steps:

1. **Perform Unconstrained Trip Assignment.** Here, initial peak hour trip tables are developed by factoring daily vehicle trip tables based on land use at the origin and destination level;

2. **Select Congested Links to be Examined.** These are links where congestion is likely to necessitate lower demand for peak hour auto travel. Key links are then examined to determine whether assigned unconstrained volumes are above the estimated maximum volumes.

3. **Sequentially Adjust Traffic Volumes for Origin-Destination Pairs in the Selected Link Trip Tables of Congested Links.** The peak reduction process decreases trips for individual origin-destination pairs according to the congestion level of the corridor in which the trips would be made. The process of making adjustments to cells in the overall trip matrix is similar to the Fratar process of matrix adjustment. Using this process the trip table is adjusted to produce the desired row and column totals in the selected link trip tables and alternates among all of the selected links until the trip table converges to the desired totals.

4. **Reassign Using Adjusted Trip Tables.** This step is necessary to reflect reroutings which are likely to occur as trip table reductions are made. Typically, trips will shift to the selected links from parallel facilities under these conditions, necessitating additional iterations to ensure that the final trip table reductions represent corresponding network routing patterns.

5. **Compare Final Link Volumes with Link Capacities.** If the assigned link volumes have not been sufficiently reduced to achieve target capacities and if significant improvements in volumes since the last assignment are indicated, the process is repeated using the new selected link trip tables. Trips in selected link trip tables for links that have met their capacity targets are not adjusted. Origin-destination pairs in the overall trip table corresponding to non-zero cells in these selected link trip tables also remain unadjusted. This limits the number of cells in other selected link trip

tables that can be used in the reduction process. The process is considered complete when the overall assignment has converged with the study area network capacity.

To make the process more practical for large models, compressed overall and selected link trip tables can be used to calculate the reductions although the original zone system should be used for traffic assignment. In a compressed trip table reduction, the same adjustments are applied to all zone-to-zone pairs comprising a district-to-district pair. The districts should be chosen so that easily identifiable corridors of travel using the selected links can be identified.

Strengths

This selective reduction, which is accomplished using "selected link analysis," is superior to global reduction (which implies a general decrease in trip generation rates) because predicted traffic volumes in uncongested corridors are not changed by unrealistic amounts.

The creation of the matrix of factors provides an important analysis capability. Specifically, conservation of the total amount of daily trips can be assured by modifying time-of-day factor matrices for the other time periods. In this way, daily assigned volumes can be obtained (by adding results of multiple time-of-day assignments).

There are two major differences between the Tri-Valley and the Boston approaches to trip table reduction to account for peak spreading:

- First, the Boston example was more "involved" in that more links were considered in the analysis. Only eight directional gateway links were considered in the Tri-Valley study.
- Second, the Boston study created a matrix of interchange-specific peak hour factors to apply to a daily trip table (in lieu of a regionwide factor), whereas the Tri-Valley study simply adjusted the assignment trip table.

Limitations

Like the link-based peak spreading approach, a major limitation to the trip reduction approach was the treatment of the trips being reduced. In the link-based peak spreading approach the trips were all assumed to occur within a three-hour timeframe regardless of capacity. In the trip reduction approach there was no explicit treatment of the trips being reduced. It is left up to the individual analyst implementing the approach as to how and when the trips being reduced show up on the transportation system. In addition, neither approach accounts for changes in traveler behavior due to congestion.

Washington D.C. Peak Spreading Model

Description

Another vehicle trip-based peak spreading procedure was developed for the Washington, D.C., area. This research was conducted as part of a larger project to develop a complete set of travel demand models for the Washington, D.C., region for travel analysis in the Dulles airport corridor. This technique is described in Allen et al, 1996. As in the link-based procedure used in Phoenix, the Washington procedure assumed that a three-hour peak period has a fixed travel demand and that trips will spread throughout the peak period.

The Washington peak spreading model was developed as a post-mode choice procedure, to be applied to a.m. peak period auto driver trips. The model was calibrated using household travel survey data and used a stratification of data by trip purpose. This stratification included home-based work (HBW), home-based university (HBU), and three non-home based trip purposes. The prevailing assumption was that the non-work trip purposes would have flatter peaking than the work and university trip purposes. Based on the survey data, home-based work and university trips had 40 percent or more of their a.m. peak period vehicle-hours of travel (VHT) occurring in the a.m. peak hour. For the non-work trip purposes, this share was 34 percent or less.

The procedure estimates the percentage of peak period travel at the vehicle trip interchange level that occurs during the peak hour based on two variables:

- Congested travel time minus free-flow travel time; and
- Trip distance.

Essentially, a set of curves relating this percentage to the travel time difference for each trip purpose was estimated from the survey data. Each curve represented a trip distance range. Examples of these curves are shown in Figure 3.3. As the travel time difference grows, more traffic can be expected to shift from the peak hour to the shoulders of the peak period.

The final model is specified in terms of a maximum share (the leftmost part of the curve), a slope (the drop in peak hour share per minute of congested time difference), a limit (which is the point ofcongested time difference at which the line begins to slope downward), and the minimum share (the rightmost part of the curve). These parameters vary by distance range and trip purpose. Thus, the mode's function is:

$$Share_d = MAX([maxshare_d + slope_d * MAX(timediff - limit_d, 0)], minshare_d)$$

where:

d = distance range

timediff = congested time-free flow time, minutes

Figure 3.3 Washington DC Peak-Spreading Model

Home-Based Other Trips

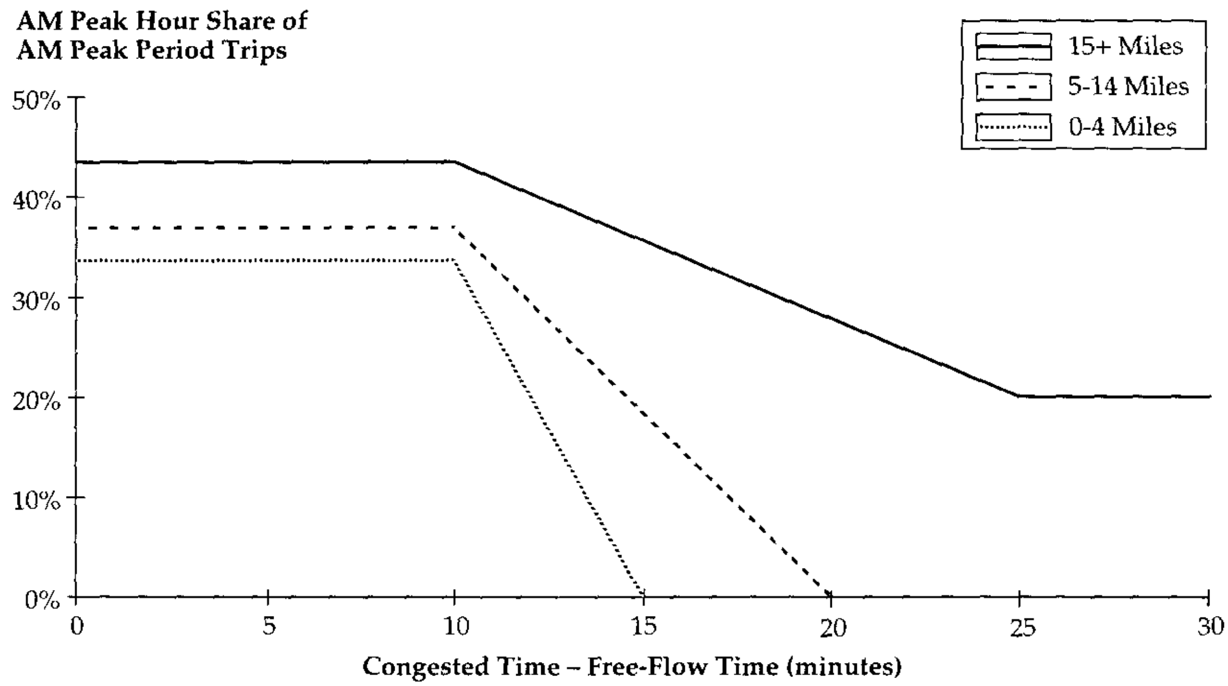


Table 3.1 lists the final peak hour share model parameters.

The number of trip distance ranges varied by trip purpose from one (for home-based university trips) to five (for home-based work trips), depending on the amount of data available for estimation. One of the key findings was that trip distance strongly influenced the peak hour percentage for work trips. Longer trips tended to had less peaking, while short trips tended to occur mainly during the peak hour. Short trips (less than five miles) have over 45 percent of the peak period trips in the peak hour, while long trips (over 35 miles) had less than 30 percent of trips in the peak hour. Trips with minimal congestion (less than five minutes) have almost 45 percent of their trips in the peak hour while trips with major congestion (greater than 25 minutes) have 30 percent of their trips in the peak hour.

Applicability

A FORTRAN program was written to apply the peak spreading model. This program reads an a.m. peak period auto driver trip table for a specific trip purpose, a matrix file containing congested travel time and distances, and a matrix file with off-peak travel times. It then applies the peak spreading model to each cell in the input trip matrix and outputs a matrix of a.m. peak hour auto driver trips.

The Washington procedure appears to be transferable to other areas. The data required for model estimation can all be obtained from a traditional household travel survey and travel model system.

Limitations

The assumption of a constant three hour peak period is a limitation of the model. While data from various regions imply that the three hour peak, as a percentage of daily trips, is fairly stable, this may simply reflect a lack of in-depth analysis of this type of information. A more rigorous peak spreading model will need to take into account trip chaining and trip tours.

■ 3.3 System-wide Peak Spreading

Description

This third method includes a systemwide peak spreading approach that has been implemented by the Volpe National Transportation System Center (VNTSC) within a modeling framework applied in evaluating Intelligent Transportation Systems (ITS). The peak spreading module included in this approach stands on its own and is not required to be used in conjunction with the full ITS Benefits Assessment Framework. It can be used with traditional travel demand models and model systems.

This peak spreading approach considers the system-wide excess travel demand and delay and distributes excess travel demand between the individual travel hours in the peak period. This approach is neither link-specific nor trip-specific; because it is

Table 3.1 AM Peak Hour Model Parameters

Purpose	Distance Range (miles)	Maximum Share	Slope	Limit	Minimum Share
HBW	0-4	0.481	-0.0200	10	0.100
	5-9	0.465	-0.0075	10	0.333
	10-14	0.456	-0.0060	10	0.333
	15-19	0.427	-0.0035	10	0.333
	20+	0.365	-0.0025	10	0.333
HBU	all	0.460	-0.0295	15	0.000
HBP	0-4	0.336	-0.0660	10	0.000
	5-14	0.368	-0.0370	10	0.000
	15+	0.430	-0.0155	10	0.200
NHB JTW	0-4	0.420	-0.0840	5	0.000
	5-14	0.437	-0.0225	10	0.100
	15+	0.490	-0.0260	10	0.100
NHB WRK	0-4	0.275	-0.0275	5	0.000
	5-14	0.430	-0.0290	5	0.000
	15+	0.480	-0.0180	10	0.300
NHB NWK	0-9	0.325	-0.0325	10	0.000
	10+	0.130	-0.0130	10	0.000

designed to model the travel impacts of ITS deployment, it assumes that a significant amount of travel information is available to travelers and thus the traveler's temporal response to congestion can be modeled on a system-wide basis rather than on a trip-specific or link-specific basis.

The overall VNTSC model framework - shown in Figure 3.4 - is an analytical tool that improves the sensitivity and capability of currently available transportation software to assess the impacts of implementing ITS user services. The model framework is comprised of a set of transportation and impact assessment models linked together by interface software facilitating the transfer of data between the models. In an iterative process, estimates of mode split and assigned traffic volumes produced by a travel demand model are input to a peak spreading module and subsequently to two macroscopic simulation models (one for freeway analysis and one for arterial analysis) via the interfaces to produce revised speeds for freeways and signalized arterials. The revised speeds are then re-input to the travel demand model. The process is iterated until the travel speeds and volumes converge, at which point the impact assessment models are used to estimate emissions, fuel, and safety impacts.

The peak spreading interface module enables the model framework to estimate congestion-dependent travel distribution within the peak period and to distribute excess travel demand among competing times of travel. An increase in traffic congestion (due to historical, recurrent, or incident-related reasons), for instance, may prompt commuters to change their departure times and travel in a different time than initially intended. In the current version of the peak spreading interface the peak period consists of three peak hours that are analyzed separately; however the methodology can be expanded to include any number of peak travel hours in the peak period.

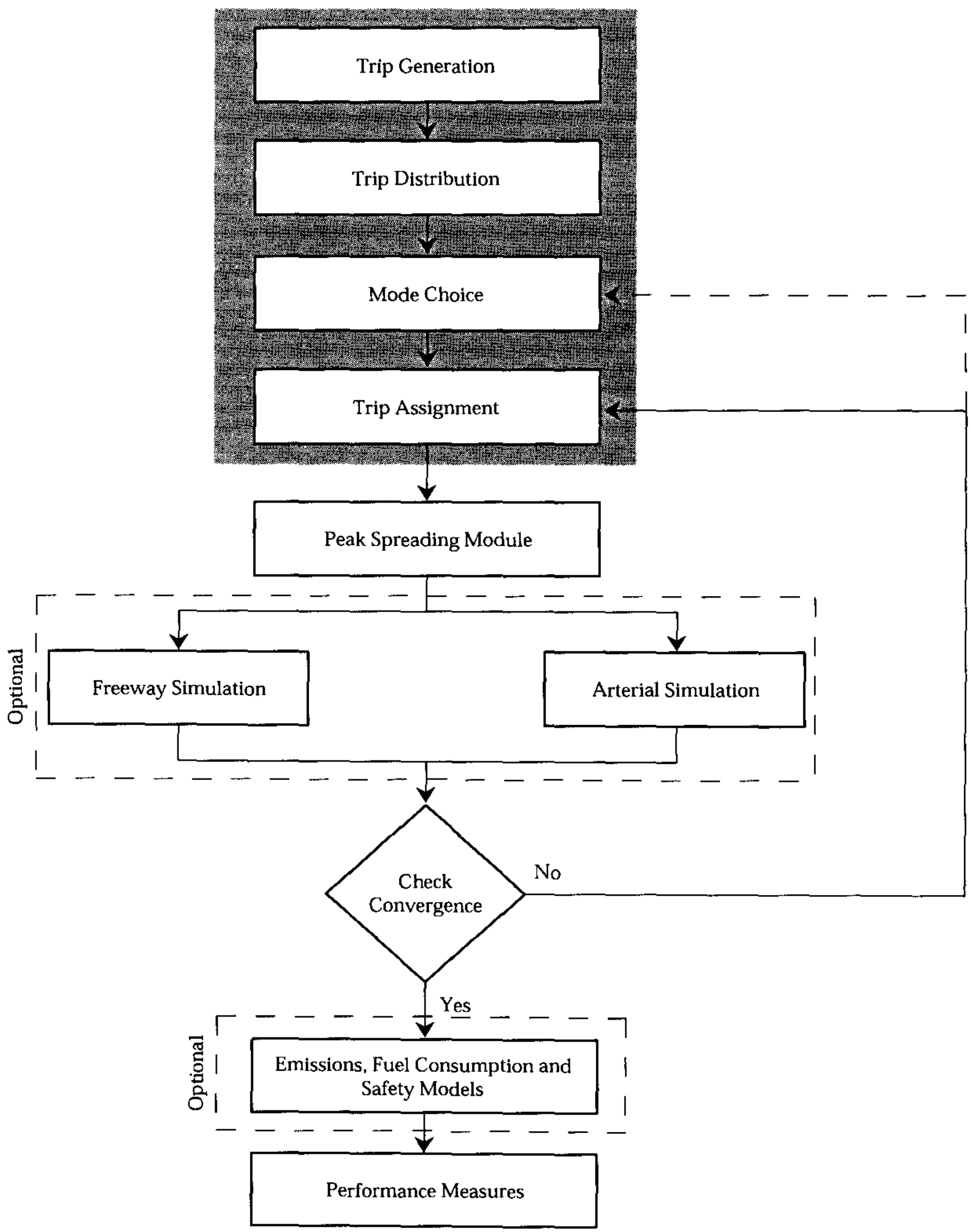
There are several analytical components in the peak spreading methodology:

- First, the user inputs information describing the time-of-day (TOD) distribution of trips in each of the three analysis hours that comprise the peak period. The TOD distribution is expressed in terms of the percentages of total daily trips that occur within each of the analysis hours. The total amount of daily trips that occur within the peak period is assumed to remain constant.

- Based on the initial TOD factors, the travel demand model produces three hourly trip assignments, producing link volumes and speeds for each of the three hours in the peak period.

- Then, a set of limits is established to differentiate between temporal and spatial diversion. The prevailing assumption here is that in the presence of congestion travelers will first divert to other routes, and after a certain amount of congestion they will divert in time. Link V/C ratios are used as aggregate measures of congestion and different V/C limits are established for each facility type. More specifically, V/C ratio limits of 1.10 and 1.05 were used for freeways and arterials, respectively. Travel demand exceeding these limits would be diverted in time only, while travel demand having V/C ratios between 1.00 and the above limits would be diverted in space (using less-congested routes in the analysis network). These spatial/temporal diversion limits were established based on data collected from 49 corridors in Arizona, California,

Figure 3.4 ITS Impact Assessment Framework – Model System Structure



and Texas; this is the same data set used in the peak spreading method that was developed for Phoenix, Arizona (Loudon et al, 1988).

- Subsequently, a mechanism was established to measure excess travel demand in each of the three travel hours in the three-hour analysis peak period. This mechanism is shown in Figure 3.5. To measure excess demand for each travel hour, the peak spreading module computes several performance measures for all freeway links with V/C ratios greater than 1.10 and for all arterial links with V/C ratios greater than 1.05; these performance measures include vehicle hours of travel (VHT), vehicle miles of travel (VMT), and vehicle hours of delay (VHD). The sum of VHD over all congested links provides a measure of excess travel demand that may be diverted temporally.

- Then, a mechanism was established to distribute excess travel demand between the three consecutive travel hours in the peak period. For each analysis hour, the ratio of VHD over total VHT is calculated and then normalized by multiplying it with the ratio of the total hourly VMT over the peak hour's VMT. This produces normalized measures of excess congestion in each of the analysis hours, which are represented as "R_i" in Figure 3.5. The "R_i" factors are then used to redistribute excess travel demand between the three analysis hours given a constant total peak period demand.

- Finally, convergence within the peak spreading module is checked by comparing the rate of change between TOD factors from one iteration to the next. When the change in TOD factors becomes less than a certain user-specified percentage, the peak spreading iterations stop and hourly link volumes and speeds are used in subsequent steps of the ITS Benefits Assessment Framework.

The peak spreading module is operationalized using code written in C++ and instructions for its use are included in the VNTSC report (*Program Reference Guide – IVHS Benefits Assessment Framework*). In this peak spreading module the user is given the option to:

- Use the peak spreading module or not; and, if yes;

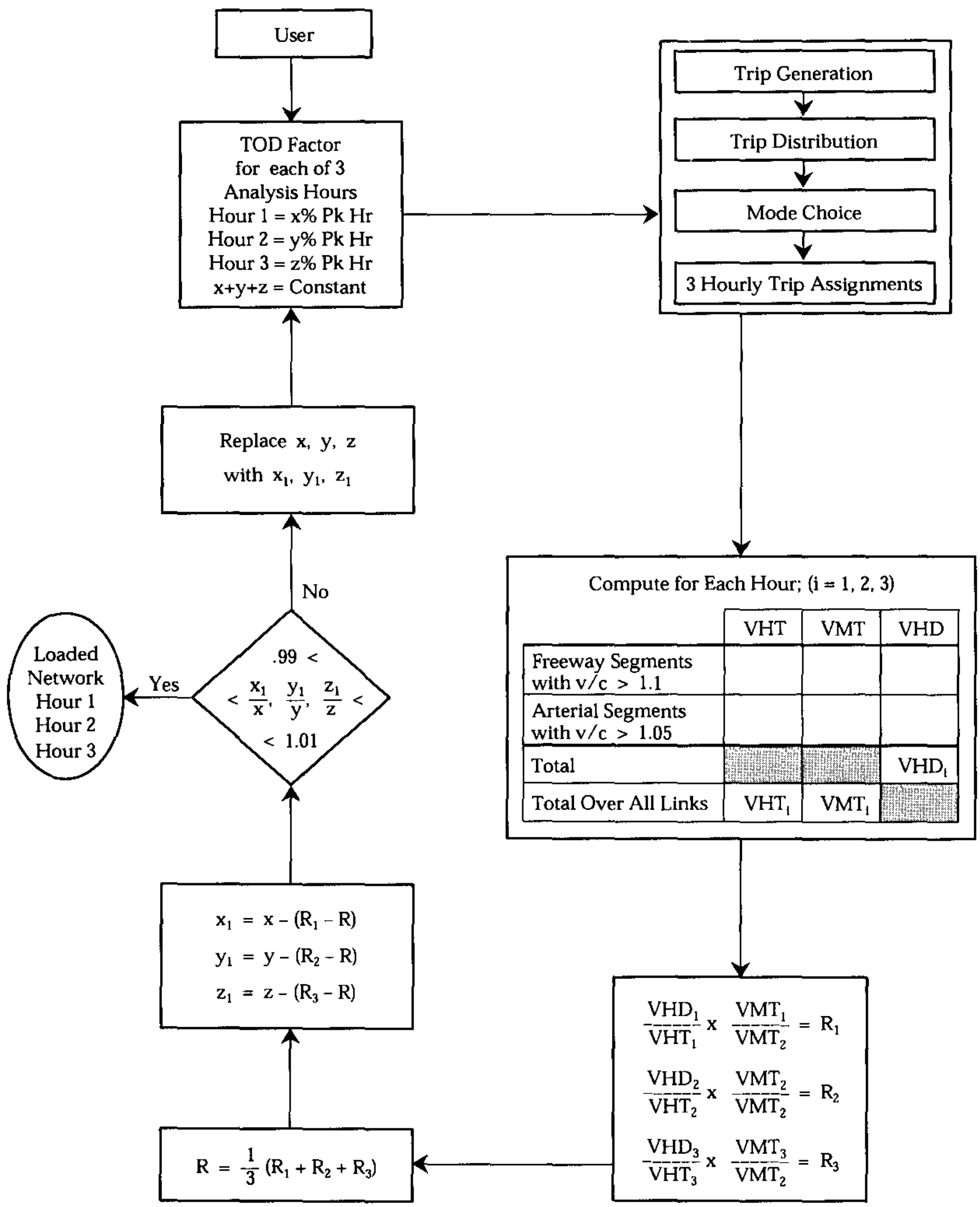
- Use a proportional peak spreading module that proportionally distributes excess travel demand over the three analysis hours based on the amount of delay that is prevalent in each hour; or

- Use a module that distributes excess travel demand only between the first two hours of the three hour peak period. This is called a "historical" or "a.m." peak spreading module because it assumes that travelers have a fixed arrival time and a flexible departure time; or

- Use a module that distributes excess travel demand only between the last two hours of the three hour peak period. This is called an "incident" or "p.m." peak spreading module because it assumes that travelers have the flexibility to divert in time only during the last two hours of the peak period.

The peak spreading module, however, stands on its own and does not require the previous use of traffic simulation models. It can be used in conjunction with the traditional

Figure 3.5 Systemwide Peak-Spreading Module
ITS Impact Assessment Framework



travel demand models run using aggregate performance measures (VHT, VMT, VHD) across facility types (freeways and arterials) produced by all travel models.

The system-wide peak spreading approach was applied in a study examining the impacts of ITS user services on the I-880 corridor in Alameda County, California. I-880 is the major north-south route serving the east San Francisco Bay Area extending from San Jose to Oakland, a distance of approximately 50 miles. This section of I-880 offers continuous alternative arterial routes located within one mile of either side of the freeway. Combinations of five types of traffic management services were evaluated using the systemwide peak spreading approach, including:

- Freeway ramp metering (demand-responsive and fixed-time);
- Arterial traffic signal coordination (demand-responsive and fixed-time);
- Integrated freeway ramp metering and arterial traffic signal coordination;
- Incident management systems; and
- High occupancy vehicle (HOV) lanes and ramp meter HOV bypass lanes

Limitations

A limitation of the system-wide peak spreading approach is that it is not sensitive to different trip purposes. For instance, work trips may be less flexible to temporal distribution than shopping or other home-based travel. It is likely that the majority of temporal shifts is associated with non-work trips.

Another limitation of the system-wide peak spreading approach relates to not being sensitive to traffic congestion on specific links or specific origin-destination flows. However, the basic premise of this approach is that significant amounts of travel information are available to travelers and thus the traveler's temporal response to congestion can be modeled on a uniform, systemwide basis rather than on a trip-specific or link-specific basis.

4.0 Emerging Approaches

This approach to time-of-day assignment is, in fact, research. This approach has not been implemented yet at either the MPO or state DOT levels. The peak spreading approaches described in the previous section do not fully address travel response to system changes and, thus, cannot be used to fully analyze policy changes or effects of travel demand management actions. The intent of this approach is to model traveler response to congestion in much the same way that mode choice is modeled. While there are no working models at present, there is potential for implementation of this procedure within the traditional four-step modeling process.

Despite the improvements in estimating time-of-day travel behavior presented previously in this section, there is a fundamental issue that remains unresolved: given that a traveler is making a trip, how does he/she decide what time to make the trip? This decision is affected by several factors, many of them unrelated to the trip or travel conditions. These include:

- Required arrival times (such as for work and school);
- Times the destination is "open" (such as for stores, offices, etc.); and
- Personal or household factors such as preferred mealtimes, other family activities, etc.

Travel condition or trip-related factors affecting time-of-day choice include:

- Level of congestion;
- Availability and level of service of transit modes;
- Auto availability; and
- Pricing differentials (parking, tolls, fares, congestion pricing).

There are at least two levels of this time-of-day choice question that need to be addressed:

1. In which period (a.m. peak, midday, p.m. peak, etc.) does the trip take place?
2. Given the period in which the trip takes place, what is the actual departure time?

The former is an important question in the analysis of such policies as congestion pricing. It is also the issue for which information is easier to obtain; transit schedules and fares, estimates of highway congestion, and other information are likely to be available by time period. In theory, it would be possible to develop a time period choice model using this information.

The second question refers to the type of information that might be used in the implementation of dynamic assignment or traffic simulation procedures. While in theory this should be conducted at a relatively continuous level, practicality dictates that "time slices" of five to fifteen minutes are the shortest intervals that could be modeled. This is due to the constraints of data. For example, survey respondents often report times to the nearest five or fifteen minutes, and traffic counts necessary for validation would not be available for shorter intervals. Perhaps a larger problem, however, is that data on which the choice would depend, such as transit level of service and congestion, would not vary enough to provide a basis for choosing a particular departure time. In addition, the types of departure time decisions reflected in route choice analysis do not seem to correspond to mode and destination choice and the decision whether to make a trip at all.

What is lacking in the innovative peak spreading approaches is a choice-based analytical approach. Through various travel surveys, we know that increasing congestion leads to the spreading of the peak period. The following traveler responses to congestion might be expected:

- **Seek Alternative Travel Route.** If excess highway capacity exists, travelers will seek alternative routes, even indirect ones, to reduce travel time. This process is currently being modeled through the equilibrium trip assignment process in microcomputer-based travel demand modeling systems. However, the limits of route diversion are not well defined. The amount of extra distance that travelers will travel might be limited. Cost-based trip assignment procedures offer some potential for solving this problem.

- **Shift Modes of Travel.** In cases where there are exclusive bus lanes, HOV lanes, or other transit options, a shift from single occupant vehicles to transit or rideshare modes is reasonable. Many mode choice models currently provide this analysis capability.

- **Change Destination.** In the case of trips where multiple alternative destinations could satisfy the trip purpose (i.e., shopping), the traveler may choose an alternative destination, even if it is less convenient from a travel distance perspective. The effect of this choice is currently modeled to some degree, especially if feedback loops are employed.

- **Stop Making the Trip.** If the trip is non-essential to the household, the trip maker can choose to not make the trip at all or satisfy the trip purpose through other means such as telecommuting, teleshopping, or chaining the trip with other, necessary travel. Typically, these choice mechanisms are not currently modeled within the traditional four-step modeling process. However, these types of strategies are approximated as part of post-travel demand modeling analysis.

- **Make the Trip at a Different Time-of-Day.** The traveler can choose to avoid peak period congestion by moving the start or end time of the activity so that the travel time does not coincide with peak period congestion on the highway network. This obvious response to increasing congestion is not currently modeled. Nevertheless, the potential exists to develop choice models along the lines of mode choice models to address this traveler option.

One commonly noted difficulty in implementing this approach is that the above choices are not independent. In reality, the decision about the time a trip is made is interlinked with the destination, mode, and route choice decisions. One purpose of TRANSIMS and other research related to activity-based modeling is to more accurately model the options and choice mechanisms of travel. Nevertheless, in the short-term, adding time-of-day choice modeling to the four-step modeling process appears to be a reasonable approach within the resources of many agencies responsible for travel demand modeling.

There are problems associated with modeling the time-of-day choice separately from other travel decisions. The problem with modeling time-of-day choice early in the four-step process is that subsequently modeled decisions have no effect on time-of-day choice. For example, modeling time-of-day choice prior to mode choice fails to consider that transit trips are more likely to occur during peak periods due to increased availability of service. Another issue is that separate models for each time period must be developed for later steps in the modeling process. On the other hand, modeling time-of-day choice later in the process assumes that time-of-day has no effect on previously modeled choices. For example, modeling time-of-day choice after mode choice fails to consider that the time the trip is taken has an effect on the mode chosen and, perhaps, the destination.

Peaking and time of travel are critical determinants of level of service, traffic congestion, and concentrations of emissions. For example, the success of strategies to reduce the intensity of highway congestion depends critically on a low elasticity of trip departure time with respect to trip duration, yet common experience on congested facilities suggests otherwise, i.e., peaks narrow but do not decline in intensity very much. Recognizing this, researchers interested in congestion relief and highway pricing have been working on a more realistic behavioral representation of peaking.

Using the example of the a.m. peak period work trip, peak spreading results from two related phenomena:

1. The adjustment of departure times in response to a perception of increased (or less predictable) door-to-door travel times. There is no effect on the timing of activities (work).

2. The rescheduling of activities to allow for a more satisfactory (or affordable) travel experience. Both trip departure and activity start times may vary.

The first phenomenon is simpler to address analytically. It implies a straightforward relationship between decreasing speeds and a broadening peak. However, this relationship may still require a resourceful extrapolation to estimate future values on the basis of current and available travel survey and count data. This analytical approach would require better-than-average estimates of travel time in the peak and off-peak period.

The second phenomenon has been the focus of much research over the past decade. This research falls roughly into four categories:

- Empirical studies of highly-congested corridors;
- Thought experiments with bottleneck queuing models;
- Econometric analyses of stated time-of-travel preference; and
- Econometric analyses of revealed time-of-travel preference.

References on this research are listed at the end of this section. The revealed preference studies, in particular, have been quite promising. They indicate substantial activity scheduling (hence, travel time) elasticities with respect to travel conditions, and suggest a close relationship among activity timing, trip generation, trip distribution (destination choice) and trip chaining.

While time of travel choice models are probably not ready to move into the mainstream of regional travel demand modeling, research has come far enough and the models are sufficiently well-behaved that their introduction into advanced modeling practice would be desirable. Several MPOs, including MTC (San Francisco Bay Area), Metro (Portland, Oregon), and SACOG (Sacramento) have proposed explicit time choice components for proposed travel demand model system updates. These proposals include the following:

- A model of time-of-day choice that predicts the period of travel as a function of variables such as free flow and congested travel times, transit level of service, trip purpose, and area type variables. This can be a logit model that could be applied after mode choice.

- A model of whether peak period trips occur in the peak hour or not. This can also be implemented as a logit model as part of a "variable demand" multiple vehicle class assignment. Use of a variable demand assignment guarantees that the results of the peak hour models are in accord with the congestion resulting from the assignment. Off peak vehicle trips would still be assigned using a traditional static demand assignment.

- A model based on a combination of traditional TOD factors and a binary time-of-day choice model. The choice model will be based on congestion represented by peak/off-peak travel times, delays, etc. The underlying hypothesis is that relatively higher congestion during peak time results in a higher likelihood of off-peak choice.

5.0 Bibliography

Abkowitz, M.D. (1981a), *An Analysis of the Commuter Departure Time Decision.* Transportation 10, pp. 283-97.

Alfa, A.S. (1986), *A Review of Models for the Temporal Distribution of Peak Traffic Demand.* Transportation Research 20B, pp. 491-499.

Allen, W.G. and G.W. Schultz. (1996), *Congestion-Based Peak Spreading Model.* Transportation Research Board.

Arnott, R., A. DePalma, and R. Lindsey. (1989), *Schedule Delay and Departure Time Decisions with Heterogeneous Commuters.* Transportation Research Record 1197, pp. 56-67

Arnott, R., A. DePalma, and R. Lindsey (1990B), *Departure Time and Route Choice for the Morning Commute.* Transportation Research 24B, pp. 209-228.

Ben-Akiva, M., A. DePalma and P. Kanaroglou. (1986), *Dynamic Model of Peak Period Traffic Congestion with Elastic Arrival Rate.* Transportation Science 20, pp. 164-181.

Cambridge Systematics, Inc. (1996), *Advanced Travel Forecasting Course – NHI Course Number 15254.* (Pilot)

Cervero, R. (1986), *Time-of-Day Transit Pricing: Comparative U.S. and International Experiences.* Transport Reviews 6, pp. 347-364.

Chang, G., and H.S. Mahmassani. (1988), *Travel Time Prediction and Departure Time Adjustment Behavior Dynamics in a Congested Traffic System.* Transportation Research 22B(3), pp. 217-232.

DePalma, A., P. Hansen, and M. Labbe. (1990), *Commuters' Paths with Penalties for Early or Late Arrival Time.* Transportation Science 24(4), pp. 276-286.

Friesz, T.L., J. Luque, R.L. Tobin, and B. Wie. (1989), *Dynamic Network Traffic Assignment Considered as a Continuous Time Optimal Control Problem.* Operations Research 37(6), pp. 893-901.

Gaudry, M.J.I., S.R. Jara-Diaz, and J.D. Ortuzar. (1989), *Value of Time Sensitivity to Model Specification.* Transportation Research 23B, pp. 151-158.

Giuliano, G., and T.F. Golob. (1989), *Evaluation of the 1988 Staggered Work Hours Demonstration Project In Honolulu.* Institute of Transportation Studies, University of California, Irvine, CA.

Golob, T.F. (1987), *A Structural Model of Temporal Change in Multi-Modal Travel Demand.* Transportation Research 21A(6), pp. 391-400.

Henderson, J.V. (1981), *The Economics of Staggered Work Hours.* Journal of Urban Economics 9, pp. 349-364.

Hendrickson, C., and G. Kocur. (1981), *Schedule Delay and Departure Time Decisions in a Deterministic Model.* Transportation Science 15, pp. 62-77.

Hendrickson, C., and E. Plank. (1984), *The Flexibility of Departure Times for Work Trips.* Transportation Research 18A(1), pp. 25-36.

Hensher, D.A. (1986a), *Statistical Modeling of Discrete Choices in Discrete Time with Panel Data, in Behavioral Research for Transportation Policy,* VNU Science Press, pp. 97-116.

Hill, D.M., L. Tittemore, and D. Gendell. (1973), *Analysis of Urban Area Travel by Time of Day.* Highway Research Record 472, pp. 108-119.

Horowitz, J.L. (1976), *Effects of Travel Time and Cost on the Frequency and Structure of Automobile Travel.* Transportation Research Record 592, pp. 1-5.

Ingene, C.A. (1984), *Temporal Influences Upon Spatial Shopping Behavior of Consumers.* Papers of the Regional Science Association 54, pp. 71-87.

Jara-Diaz, S.R. (1990), *Consumer's Surplus and the Value of Travel Time Savings.* Transportation Research 24B, pp. 73-77.

Loudon, W., E. Ruiter, and M. Schlappi. (1988), *Predicting Peak-Spreading Under Congested Conditions.* Transportation Research Record 1203

Mahmassani, H.S., and G. Chang. (1985), *Specification and Estimation of a Dynamic Departure Time Acceptability Model in Urban Commuting.* Working Paper, Department of Civil Engineering, University of Texas, Austin, TX

Mahmassani, H.S., and G. Chang. (1988), *Dynamic Aspects of Departure Time Choice Behavior in a Commuting System: Theoretical Framework and Experimental Analysis.* Transportation Research Record 1037, pp. 88-101.

Mahmassani, H.S., and G. Chang. (1986), *Experiments with Departure Time Choice Dynamics of Urban Commuters.* Transportation Research 20B(4), pp. 297-320.

Mahmassani, H.S., and R. Herman. (1984), *Dynamic User Equilibrium Departure Time and Route Choice on Idealized Traffic Arterials.* Transportation Science 18, pp. 362-384.

Mahmassani, H.S., and D.G. Stephan. (1988), *Experimental Investigation of Route and Departure Time Choice Dynamics of Urban Commuters.* Transportation Research Record 1203, pp. 69-84.

Moore, A.J., P.P. Jovanis, and F.S. Koppelman. (1984), *Modeling the Choice of Work Schedule with Flexible Work Hours.* Transportation Science 18(2), pp. 141-164.

National Association of Regional Councils. (1993), *A Manual for Regional Transportation Modeling Practice for Air Quality Analysis.* Version 1.0 Washington, D.C.

Polak, J., P. Vythoulkas, and P. Jones. (1992), *An Assessment of Some Recent Studies of Travelers' Choice of Time of Travel.* University of Oxford Transportation Studies Unit, Oxford, UK.

Rossi, T.F., E.R. Ruiter, and E.A. Harper. (1990), *A Procedure to Reduce Trip Tables to Reflect Network Capacity Constraints.* Transportation Research Board Preprint Paper.

Urban Mass Transportation Administration (now FTA). (1986), *Procedures and Technical Methods for Transit Project Planning.* Review Draft, Washington, D.C.

Volpe National Transportation Systems Center. (1994), *IVHS Benefits Assessment Model Framework.* Final Report, Cambridge, MA.

Volpe National Transportation Systems Center. (1994), *Program Reference Guide - IVHS Benefits Assessment Framework.* Cambridge, MA.

6.0 Terminology

Algorithm	A step-by-step procedure for computing a solution to a mathematical problem.
All-or-nothing assignment	Allocation of the total number of trips between two zones to a single path, usually on the basis of the minimum travel time.
Auto ownership	The number of passenger vehicles available to a household for routine daily travel. Because an individual's choice of transportation mode depends strongly on vehicle availability, average vehicle availabilities for households with similar income characteristics are considered a basic zonal descriptor.
Bottleneck	The point of minimum capacity along a highway segment.
BPR	The U.S. Bureau of Public Roads, now Federal Highway Administration.
BPR Equation	A formula suggested by the BPR for calculating travel time as a function of volume on a highway link.
Caltrans	California Department of Transportation.
Capacity constrained	A traffic assignment procedure that places trips on multiple origin-to-destination paths, taking into account the effects of congestion.
CARB	The California Air Resources Board.
CCCTA	Central Contra Costa Transit Authority.
Choice set	The set of alternatives from which a consumer may choose.
CMP	Congestion Management Plan.
Congestion	Interference of vehicles with one another as they travel, reducing speed and increasing travel time. Travel time on a link increases as an exponential function of the ratio of the number of cars on the link (volume) to the link's capacity. At low volumes, links are said to be uncongested, since vehicles do not interact much; as volumes approach capacity (defined as the maximum flow rate at the most constructed point on a link), congestion effects become increasingly apparent and travel time increases noticea-

bly. The volume of entering vehicles may exceed the capacity of the link, in which case the excess vehicles form a queue within the link, link traversal times increase exponentially, and flow exits the link at capacity rates.

CTPS The Central Transportation Planning Staff of the Massachusetts Executive Office of Transportation and Construction. CTPS performs the analytical functions of the MPO for metropolitan Boston.

Delay The difference between the actual time spent traversing a link and the free-flow (unimpeded) time.

Destination The zone in which any trip terminates.

Destination choice Given that a trip will be made, the purpose of the trip, and the trip's origin (see trip generation), the destination choice process simulates an individual's choice of the location at which the activity associated with the trip's purpose will be carried out. This generally refers to a method for performing the trip distribution function.

Deterministic Not stochastic.

Disaggregate models In common usage, models developed to represent the behavior of individual decision-makers (persons, households, firms).

Discrete choice A modeling approach depicting choice among readily definable and distinct alternatives.

DOT A state or federal Department of Transportation.

EMME/2 A computer software package for transportation network and travel demand analysis.

EPA The United States Environmental Protection Agency.

Equilibrium Any complex system that has attained its highest entropy steady-state operating condition is said to be in equilibrium. The traffic assignment process has reached equilibrium when a change of route by any traveler would increase travel time, for the individual traveler if trips are assigned using the user-optimal decision rule, or the total time for all travelers if the system-optimal principle is used.

Expert system A modeling approach that incorporates human judgment and expertise, both quantitative and qualitative, in a decision-oriented framework.

Feedback — Using the results of one step in the modeling process to recalculate a previous step. For example, the link volumes from traffic assignment can (and should) be used to recalculate first travel speeds and then trip distribution, since the first pass through trip distribution employs only an approximation of link speeds.

FHWA — The United States Department of Transportation, Federal Highway Administration.

Fratar method — A method used extrapolating trip distribution on the basis of growth factors for both the origin and the destination, named after its developer.

FREQ — Freeway Queuing model (A.D. May).

FTA — The United States Department of Transportation, Federal Transit Administration (formerly UMTA).

Functional classification — The classification of urban roadways by function. Roadways at the top of the hierarchy serve intercity and other long-distance movement of traffic, roadways at the bottom provide access to land.

Generalized price — A numerical expression capturing both the time costs and the dollar costs affecting travel behavior.

Gravity model — A trip distribution model which represents trip exchanges as a product of attractions and productions divided by an exponential function of travel costs (usually measured only by travel times).

HBW — Home-based work.

HCM — Highway Capacity Manual.

Home-based — Starting and/or ending at home.

Home-based work — A trip with one end at work and the other at home.

Household travel survey — A survey seeking to determine the travel habits of a household, and characteristics of the household which are relevant to its travel behavior, such as auto ownership, number of occupants, income, etc. The survey usually consists of a questionnaire and a "travel diary" which asks each member of the household to record trips taken during the survey period (usually a day). Recently, "activity" surveys have been performed.

HOV High-occupancy vehicle.

HPMS Highway Performance Monitoring System, a federally-mandated database consisting of a representative sample of highway links.

Induced demand Travel demand alleged to result from added transportation capacity or reduced transportation price.

Interzonal Between two different zones.

Intrazonal Within a single zone.

ISTEA The Intermodal Surface Transportation Efficiency Act of 1991.

ITS Intelligent Transportation Systems.

K-factors Adjustment factors applied to trip distribution models representing, in theory, social, economic, and geographic conditions that affect travel patterns but are not included in the model specification. In practice, K-factors are simply added to improve the fit of trip distribution models to observed data.

Latent demand Travel demand said to be suppressed by lack of capacity, high price, etc., which will materialize if such impediments are removed.

Level of service In general, a set of metrics or qualitative descriptors of a transportation system's performance. Matrices of interzonal travel times and costs are sometimes called "level of service tables;" the Highway Capacity Manual (NCHRP, 1985) defines levels of service for intersection and highway operations, with ratings that range from A (best) to F (worst).

Link An element of a transportation network, a representation of a guideway segment, terminating in a node at either end. A link may have a number of attributes, including distance, number of lanes, capacity, and directionality, and is often assigned a function which relates travel time on the link to the volume of traffic using the link.

Logit A choice model formulation based on the principle that individuals maximize utility in choosing among available alternatives. The logit formulation involves specifying a utility function for each individual, with a deterministic component (that is, one which depends on characteristics of the individual and of the alternatives) and a stochastic disturbance (or error term).

LOS Level of Service.

Macroscopic model A model that describes traffic flow in the aggregate.

Matrix A multi-dimensional table of numbers.

Microscopic model A model that describes traffic flow in terms of individual vehicles.

Microsimulation A demand simulation focusing on the behavior of individuals and households.

MinUTP A transportation demand modeling package.

Mode choice A process by which an individual selects a transportation mode for use on a trip or trip chain, given the trip's purpose, origin, and destination; characteristics of the individual; and characteristics of travel by the realistically-available modes. Mode choice is placed either before or after trip distribution in a conventional modeling sequence. Some model systems determine mode choice jointly with destination choice for some trip purposes. Multinomial logit is the formulation used for mode choice in the vast majority of cases.

Mode split The percentage, or share, of trips captured by the various transportation modes.

MPO The Metropolitan Planning Organization designated by the state to carry out various federal urban transportation planning mandates.

MTC The Metropolitan Transportation Commission, MPO for the nine-county San Francisco Bay Area.

Multinomial logit A logit model of choice among more than two alternatives. A logit model for choosing between two alternatives is "binary logit."

NARC The National Association of Regional Councils, a Washington-based voluntary association of MPOs and other regional planning organizations.

NCHRP National Cooperative Highway Research Program.

Nested logit	Hierarchical application of the logit formulation. Nested logit is used for choices in which some alternatives are more similar than others (e.g., 2-person carpools and 3-person carpools appear to be more alike than either is to public transit). In these cases, the assumption of full independence in the utility error terms cannot be justified. Conceptually, nested logit analysis involves the grouping of similar alternatives into one or more "secondary" logit models, with a "primary" choice among the bundles of similar alternatives.
Network	A mathematical representation of an area's transportation (or communication) facilities, composed of links and nodes.
NHB	Non-Home Based.
Node	A point where two links join in a network, usually representing a decision point for route choice but sometimes indicating only a change in some important link attribute.
Non-Home Based	A trip which neither begins nor ends at home.
Off-peak	Occurring during periods of relatively low traffic, not during a peak.
Origin	The location or zone at which a trip begins; the place where a trip is "produced." (See also trip generation, trip production, trip distribution.)
Path	A route through a network; a series of links and nodes connecting an origin and a destination.
Peak	Whether categorized by purpose or by geographic area, trips occur at different rates at different times of the day. A graph of trips by time of day typically reveals one or more peaks. These peaks play a key role in conventional travel demand analysis, which focuses on maximum infrastructure needs in each corridor. The dominant weekday peaks are in the morning ("AM Peak") and the late afternoon ("PM Peak"), obviously related to the timing of work trips. A peak can be characterized by its maximum trip rate (in trips per unit time) or by a duration over which some threshold trip rate is maintained. The portions of the peak before and after the peak hour are called the "shoulders of the peak."

Peak hour — The hour during which the maximum traffic occurs. The peak hour during which traffic is highest varies from link to link and place to place, a fact which is not fully reflected in traditional travel demand analysis.

Peaking factor — The ratio of vehicle trips made in a peak period to vehicle trips in some given base period, usually a day.

Peak-hour factor — 1) The ratio of traffic volume in the peak period to Average Daily Traffic. 2) In critical movement analysis, a measure of peaking characteristics within the peak hour, usually calculated as the ratio of traffic volume in the peak hour to the traffic volume in the 15 minutes with the highest volume. Intervals shorter than 15 minutes are sometimes used, depending on the purpose of the analysis.

Peak Spreading — Lengthening of the peak period, usually accompanied by a flattening of the peak.

Person trip — The movement of a person from an origin to a destination, as opposed to the vehicle trip associated with the same origin-to-destination movement. A carpool carrying three people from origin-to-destination has made one vehicle trip, its occupants together have made three person trips.

Regression — A mathematical technique for exploring relationships between sets of observations on two or more variables. A functional relationship between the variables is postulated, and line or curve fit between the plotted observations so as to minimize some function (usually the square) of the deviations between the plotted points and the line or curve. The result is the equation of the best-fit line or curve describing the dependent variable in terms of the other variables, which is often used for predictive purposes; and measures of how goodness-of fit. If the postulated relationship is a line, the technique is called linear regression.

Revealed preference — A preference which is identified through analysis of actual choices and the conditions under which they were made.

Ridesharing — Providing multiple person trips per vehicle trip. Ridesharing modes include carpools, vanpools, taxis (sometimes), shuttles, jitneys, dial-a-ride, etc. Bus and rail transit are technically forms of ridesharing although they are generally treated as a separate mode.

RMSE — Root Mean Square Error.

Route choice	The process of simulating the sequence of roadways an individual will choose for a trip, given the trip's origin and destination, and mode. Route choice is generally the task of the traffic assignment phase in the model sequence, and is based on the assumption that an individual will choose the route that will minimize travel time (or cost) for that trip. For mass transportation, route choice is usually straightforward for all but the largest systems, and does not require equilibrated traffic assignment procedures.
RTIP	Regional Transportation Improvement Program, a compilation of projects to improve a region's transportation system, designed to be implemented in the short-to-medium term.
RTP	Regional Transportation Plan, the long-range plan for investing in transportation facilities in a region.
SACOG	Sacramento Area Council of Governments.
Sample enumeration	A method of microsimulation based on calculations made for each individual observation which are later aggregated to represent the full sample or population.
SCAG	Southern California Association of Governments.
SCAQMD	South Coast Air Quality Management District.
SIP	A State Implementation Plan developed under the Federal Clean Air Act to improve air quality.
Sketch planning	Simple, approximate methods of analysis used to provide initial estimates of impact or to "screen" projects for which more detailed analysis would be worthwhile.
SOV	Single Occupant Vehicle.
Stated preference	A preference which is stated by the consumer when offered several hypotentical choices and a description of the conditions under which they would be made available.
Stochastic	Characterized by randomness; having a random component.
Supply	The character of the transportation system that determines its operating performance.
TAZ	Traffic Analysis Zone.
TCM	A Transportation Control Measure for emissions reduction.

TDM Travel Demand Management.

TIP The regional Transportation Improvement Program, a federally-required MPO listing of pending highway and transit projects.

TODF Time of Day Factor.

Traffic assignment A process by which trips, or flows among zones, are allocated to feasible routes (paths) through a network.

Tranplan A software system for transportation modeling.

TRB Transportation Research Board.

Trip attraction The process of attracting trips to a zone. A trip terminating or originating in a zone whose existence is due to an activity carried out in the zone is said to be "attracted." Trip attraction is generally a function of the land uses in a zone.

Trip chaining The traveler's process of linking trips into tours. A trip chain, or tour, is defined such that the destination of the first trip is the origin of the second, the destination of the second trip is the origin of the third, and so forth.

Trip distribution The process of determining trip exchanges, that is, the number of trips between each pair of zones. Trip generation results - trip origins and destinations, or trip productions and attractions, depending on the methodology in use - are input to the trip distribution process, the outputs of which are trip tables (matrices) with each cell containing the number of trips between a pair of zones. The most common trip distribution analysis technique is the gravity model, although intervening opportunities and logit formulations are also common.

Trip frequency The number of trips per unit time.

Trip generation The process of determining the number of trip origins and destinations associated with a given set of activities in a given area, usually by applying trip rates (or a cross-classification or regression model) to a land use inventory or projection. In a regional travel demand study, trip generation is done at the zone level and requires detailed descriptions or projections of land use for each zone. For a traffic impact analysis, it is done at the project level and requires a tabulation of the square footage devoted to each activity the project accommodates. The outputs of trip generation analysis are one-dimensional arrays of origins and destinations for each zone which become the input of trip distribution analysis.

Trip production — The process of producing trips from a zone. A trip originating or terminating in a zone whose existence is due to the traveler's residence in the zone is said to be "produced" there (the terminology is less clear for non-home-based trips). Trip production is generally a function of the residential lane uses in a zone.

Trip purpose — A classification of trips by their preceding and/or following activities ("purposes"). For computational reasons, conventional travel demand models typically employ a small number of trip purposes such as "home-work," "home-shop," "home-other," and "non-home-based." (A category such as "home-work" usually comprises both home-work and work-home trips.)

Trip rate — For a given type of land use or geographic area, the number of trips per unit time per unit size. The Institute of Transportation Engineers maintains a widely-used catalog of average trip rates for a large number of land use types. Trip rates are estimated via any of a number of techniques, including cross-classification, linear regression, and multiple regression.

Trip table — A table, or matrix, showing the number of trips made from every zone in a network to every other zone, in a given time period, and for a given trip purpose or set of purposes. Trip tables are the product of the trip distribution phases of the travel demand process.

Utility — In transportation modeling, the value (positive or negative) of a particular option, usually estimated as a function of the travel option's characteristics as well as traveler or population characteristics.

UTPS — The Urban Transportation Planning System, a transportation modeling package developed in the 1970s by the U.S. Department of Transportation for use on mainframe computers. While UTPS continues in use by a number of large MPOs, it is no longer officially maintained.

Vehicle trip — An origin-to-destination journey by a single vehicle, as opposed to a person trip, the origin-to-destination journey of an occupant of the vehicle. A bus carrying 40 people from an origin to a destination makes one vehicle trip, while its occupants make a total of 40 person trips.

VMT — Vehicle-miles traveled.

Volume-delay function — A functional relation between the volume and the speed of travel on a facility.

Zone

The basic geographical unit for conventional travel demand analysis. A study area is divided into zones, the number and size of which depend on the size and land use patterns of the area, the geometry of the roadway network, the nature of the problem, the computing resources available, census boundaries, and political boundaries. Zone boundaries are defined so that land uses and activities within are homogenous, to the extent practicable.

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