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

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 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.

Figure 2.1 Time-of-Day Modeling After Trip Assignment

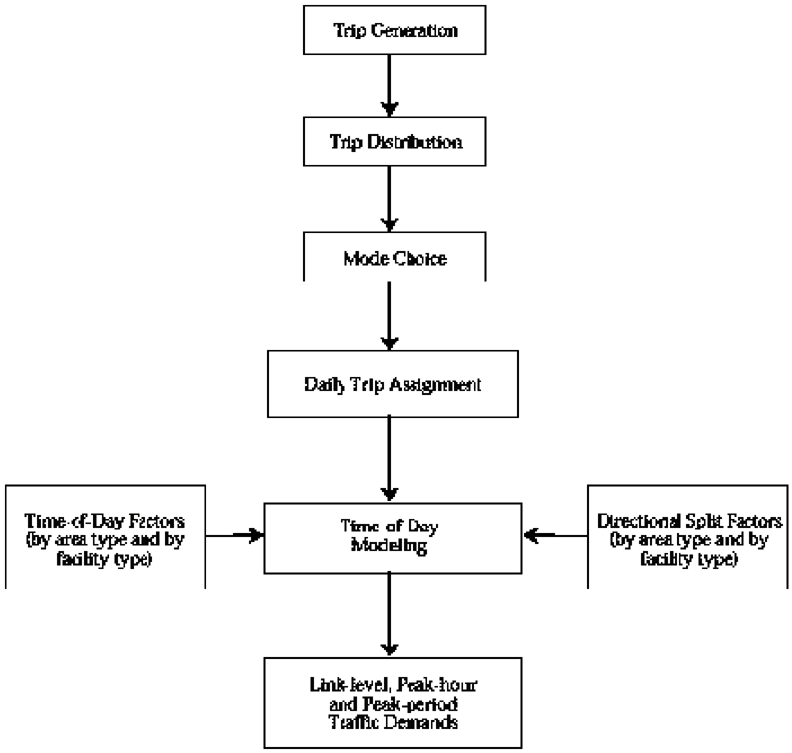


Table 2.1 Post-Assignment Static Technique - Peak Hour Percentages

Facility Type	**Area Type**				
	CBD	**Central City**		**Suburban**	
	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.					

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 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, 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

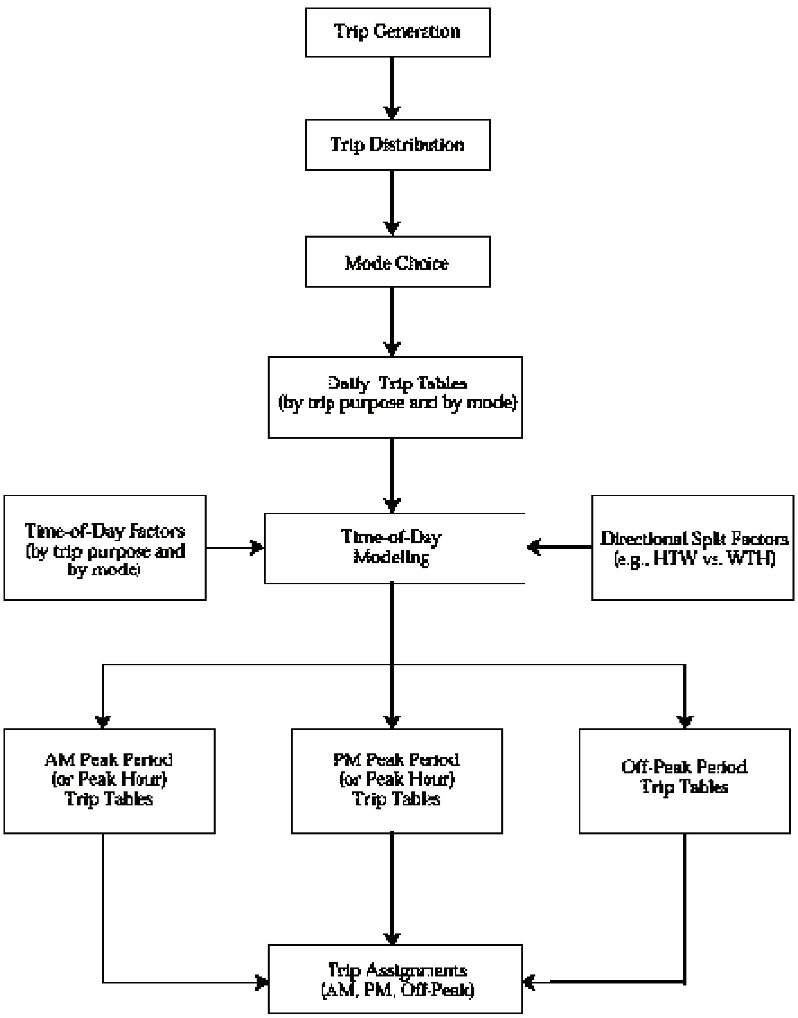


Table 2.2 Post-Mode Choice Auto Time-of-Day Factors

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 P-A A-P	25.7 25.1 .6	15.5 15.2 .28	24.1 2.1 21.98	14.48 1.10 13.38	3.53 1.44 2.09
HBO P-A A-P	6.93 5.12 1.8	3.2 2.48 .72	16.08 6.22 9.86	8.25 3.20 5.05	6.85 3.23 3.62
NHBW P-A	11.65 2.37	6.81 .77	24.26 22.86	12.86 12.28	7.97 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 P-A A-P	42.82 42.82 0	35.86 35.86 0	5.04 0 5.04	1.89 0 1.89	23.27 0 23.27
HBC P-A A-P	25.01 24.25 .75	16.67 16.07 .60	11.46 2.97 8.49	5.5 1.78 3.72	9.38 1.64 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	7:00-9:00	AM PK 7:15-8:15	PM 2 HR 3:30-5:30	PM PK 4:30-5:30
HBW P-A A-P	32.08 31.79 .28	15.46 15.31 .14	30.63 1.01 29.62	21.53 .43 21.09
HBO P-A A-P	1.35 1.35 0	.54 .54 0	14.4 5.4 8.96	6.79 2.44 4.34
NHBW P-A A-P	8.69 1.74 6.95	2.89 .77 2.12	21.74 20.48 1.26	11.59 11.20 .39
NHBNW	0	0	22.07	7.7
HBS P-A A-P	43.65 43.65 0	26.90 26.90 0	12.7 0 12.7	3.05 0 3.05
HBC P-A A-P	32.51 31.53 .98	18.4 17.66 .74	11.05 2.87 8.17	4.92 1.58 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.

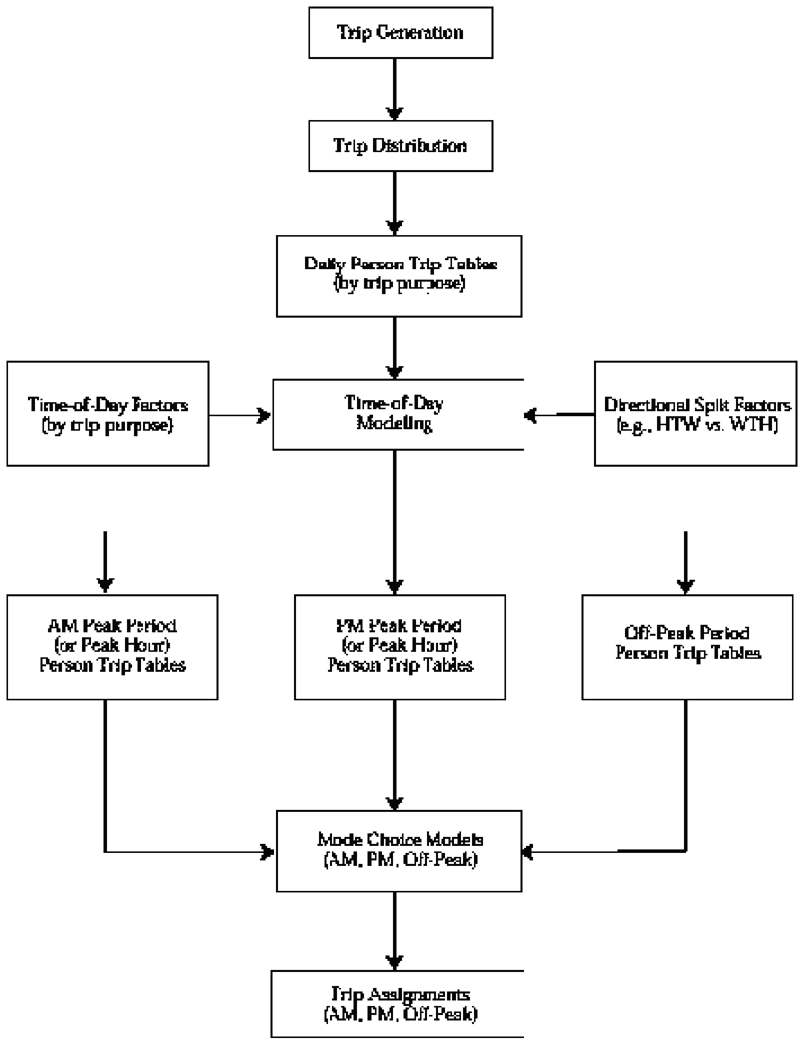
Many of the adjustments being made to trip tables are intended to better cope with modal, facility, corridor, and subregional variations in peaking. Recently, some agencies have developed ad hoc procedures which draw upon empirical studies to estimate the probable impact of congestion on peaking levels 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 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.

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



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

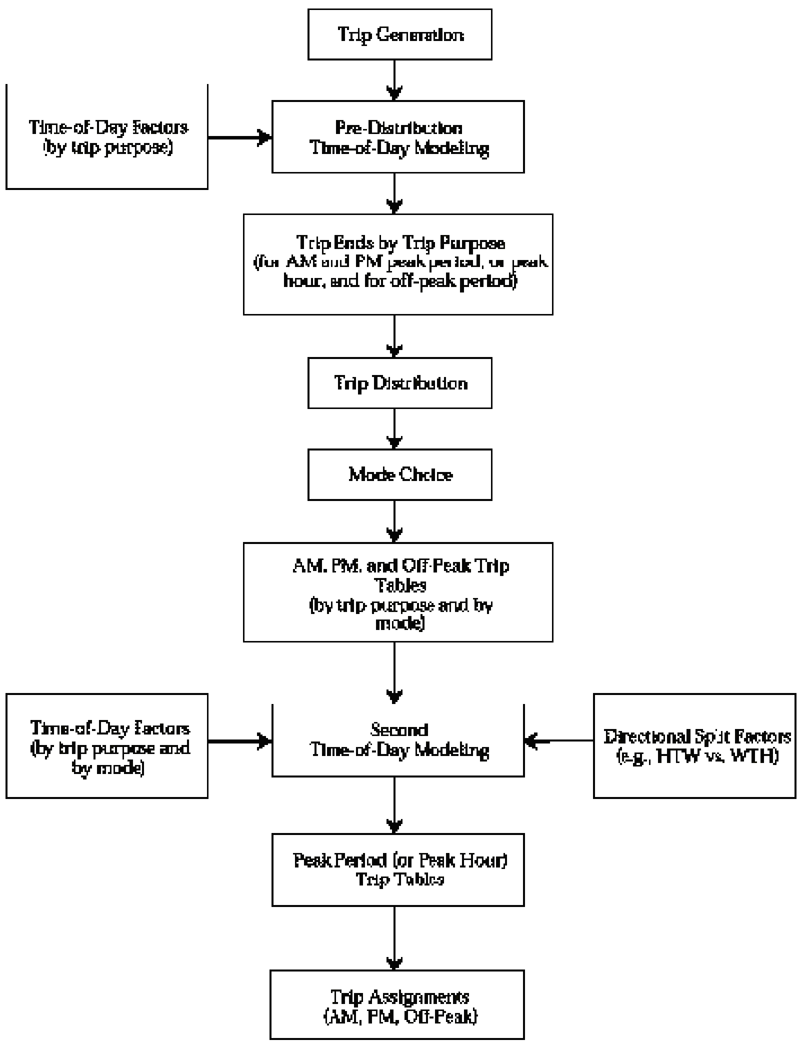
Description

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

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



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. FTA (UMTA, 1986) 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."

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. UMTA (1986) 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."