Practical Approach to Deriving Peak-Hour Estimates from 24-Hour Travel Demand Models

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The Clean Air Act Amendments of 1990 have created a need for accurate and reliable estimates of peak-period travel and the speeds at which vehicles operate during that time period. State transportation agencies are faced with the problem of generating the volume and speed data needed to develop mobile source emissions inventories. This problem is compounded by the absence of current time-of-day travel characteristics. Although some of the software vendors that developed programs for the four-step travel demand forecasting process are also developing postprocessors that prepare the 24-hr model output for input to the emissions calculations models, a critical need to be able to respond to clean air agency needs required the development of an immediate response mechanism. The focus is on the application of a travel demand model and an annual traffic count program as the prime ingredients for a process that can be used to convert the 24-hr travel demand model output to peak-hour estimates of travel. The approach is a practical, how-to procedure that enables the user to estimate volumes and speeds for any hour of the day and for any day of the year, with the ultimate objective of preparing a base year inventory of mobile on-road emissions. Current data sources are evaluated and applied in the process.

The need for peak-hour travel information, particularly estimates of vehicle miles traveled (VMT), has become more pronounced since the Clean Air Act Amendments of 1990 requirement for mobile source emissions inventories to establish conformity. There are several sources of estimated VMT on a transportation network:

- Link-based VMT estimates from regional or statewide traffic counts and roadway segment lengths;
- VMT estimates from fuel sales, vehicle registrations, roadway mileage, population, or a combination of these data;
- Highway Performance Monitoring System estimates for VMT, which are basically derived from traffic count data; and
- Travel demand forecast model estimates of VMT and network travel speeds.

Because most states have some type of travel demand models at the urban, regional, or statewide level, the information generated by these models is a readily available source of future travel estimates that can serve as a base for emissions estimates. The 24-hr models available in these areas usually generate average annual daily traffic (AADT) forecasts that were originally developed to project travel for corridor-level analyses. Some of the software vendors who developed commercial programs to process the traditional four-step travel demand models are developing postprocessors that prepare 24-hr model output for input to the emissions calculation phase through the application of user-provided factors or program-supplied default values.

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The Delaware Department of Transportation (DelDOT) is one of the agencies required to develop a credible and viable base for calculating emissions for an evening peak 2-hr period. The DelDOT preferred not to use generalized factors or default values in its efforts to derive emissions estimates. The needs are further compounded by the requirement that speeds for the travel conditions during the peak period also must be available. In its effort to prepare accurate and reliable motor vehicle emissions for New Castle County (NCC), DelDOT required a process that would provide an opportunity to examine potential emissions levels under a variety of temporal conditions. Estimates of vehicular travel for daily peak periods are required, with an ability to also provide estimates on a seasonal basis. The resulting VMT estimates for 1990 were used to develop a 1990 mobile on-road emissions inventory for the Department of Natural Resources and Environmental Control, the state's clean air agency.

The approach and procedure used to convert DelDOT's NCC 24-hr travel demand model to volume and speed estimates for a 2-hr evening peak period are described. Because of time constraints the technique had to rely on existing data, be practical, and produce credible results.

APPROACH

Two components of model-generated estimates need to be addressed: zone-to-zone travel and intrazonal travel. The approach to converting the zone-to-zone estimates generated by the 24-hr models to a peak period relies basically on the manipulation of the existing procedures to enable the user to factor certain of the trip tables that make up the eventual assignment. The method presumes that a valid and calibrated model is available, which is the case with DelDOT. The NCC model configuration is the traditional four-step generation, distribution, model split, and assignment technique. The method for converting 24-hr model data to the peak period is relatively simple in concept and straightforward in application. The trip tables created by the distribution process for internal-internal (I-I) and external-internal (E-I) movements are factored by values that represent the percentage of travel in NCC during the desired hours. External-external (E-E) travel has two basic components of interest: truck and nontruck. These movements are factored by a similar approach. The key to this process is dependent on the availability of the data required to establish the necessary factors.

Three different approaches were considered for this task:

1. Across-the-board factoring of 24-hr link volumes by one average peak period factor,
2. Application of selective peak-period factors, on the basis of traffic count data to different functional classes of roadway, and
3. Adaptation of the 24-hr travel demand model through the application of peak-hour factors by purpose and type of movement.

Some advantages and disadvantages of each approach are given in Table 1. The comparisons are relative to each other and assume that the 24-hr model assignments are generated by a calibrated model.

DelDOT considered the first two approaches to be too generalized and decided to pursue the travel demand model option. The adaptation of the 24-hr model to peak hour is based on the ability to apply peak-hour factors to the various travel components of the system by movement (I-I, E-I, and E-E) and by purpose (work, shop, other, school, non-home-based, and trucks). Trucking is technically a mode but is treated here as a purpose.

The focus in this effort was on the evening peak period, but it can be applied to morning, midday, or anytime of the day by any day or season of the year. For example if peak period volumes are required for days in August considered to be the "hot" days, this approach is also applicable.

Because a 120-min peak period was identified for the emissions calculations, the procedure was applied to two evening peak hours (in this case 4:00 to 5:00 and 5:00 to 6:00 p.m.) separately. This approach is necessary because in the assignment process hourly capacities are used for restraint values. The emissions calculations are performed for each of the peak hours and are summed to obtain a value that represents a peak period.

ZONE-TO-ZONE VMT ESTIMATES

Procedure

If a 24-hr model has been run for the specific year for which emissions calculations are required, the basic components are available and the procedure for the peak-hour processing can be initiated.

The initial steps are concerned with the usual procedures for building a binary network, skimming trees, and updating the skim trees with intrazonal and terminal times. The key difference for peak-hour model processing is that the highway link data records must contain roadway capacities that are expressed in hourly capacities rather than 24-hr capacities. The NCC procedures create trip tables by purpose for the I-I and E-I movements for 24-hr travel as presented in Table 2.

The I-I person trips are subjected to the model-split process to generate two trip tables: one for transit person trips and one for nontransit person trips. Vehicle occupancy factors, by purpose, are applied to the nontransit person trip table to create a vehicle trip table for the I-I movements. At this point in the process the trip tables represent vehicular AADT volumes and are ready for conversion to peak-hour volumes. Special treatment was applied to certain purposes and movements as shown in Figure 1 and described below.

Convert Work Trips to Peak Hour

The I-I and E-I home-based work (HBW) trip tables are treated differently from those for nonwork purposes because of the peaking characteristics. Work trips tend to be concentrated in the morning and evening. The structure of the trip generation and distribution models creates trip tables that are essentially unbalanced

TABLE 1 Advantages and Disadvantages to Approaches to Converting 24-hr Model Data to Peak Period

Approach	Advantages	Disadvantages
Across-Board Factoring	- Ease of application	- Too general - Does not generate speed data - Questionable reliability at link level
Link Factoring	- Relatively simple application	- Estimates are average and not focused on peaks - Does not generate speed data
Travel Demand Model Adaptation	- Refines estimates by considering trip purpose - Ability to separate truck and non-truck travel - V/C ratios are based on peak hour volumes and capacities - Provides speed data associated with time period - Directional splits can be obtained	- More complex procedure - Requires detailed traffic count data - Requires hourly data by purpose

TABLE 2 NCC Trip Purpose Categories

Movement	Purpose: Person Trips	Purpose: Vehicle Trips
I-I	HB Work HB Shop HB Other NHB	Truck/Taxi School
E-I		Trucks Work Shop Other

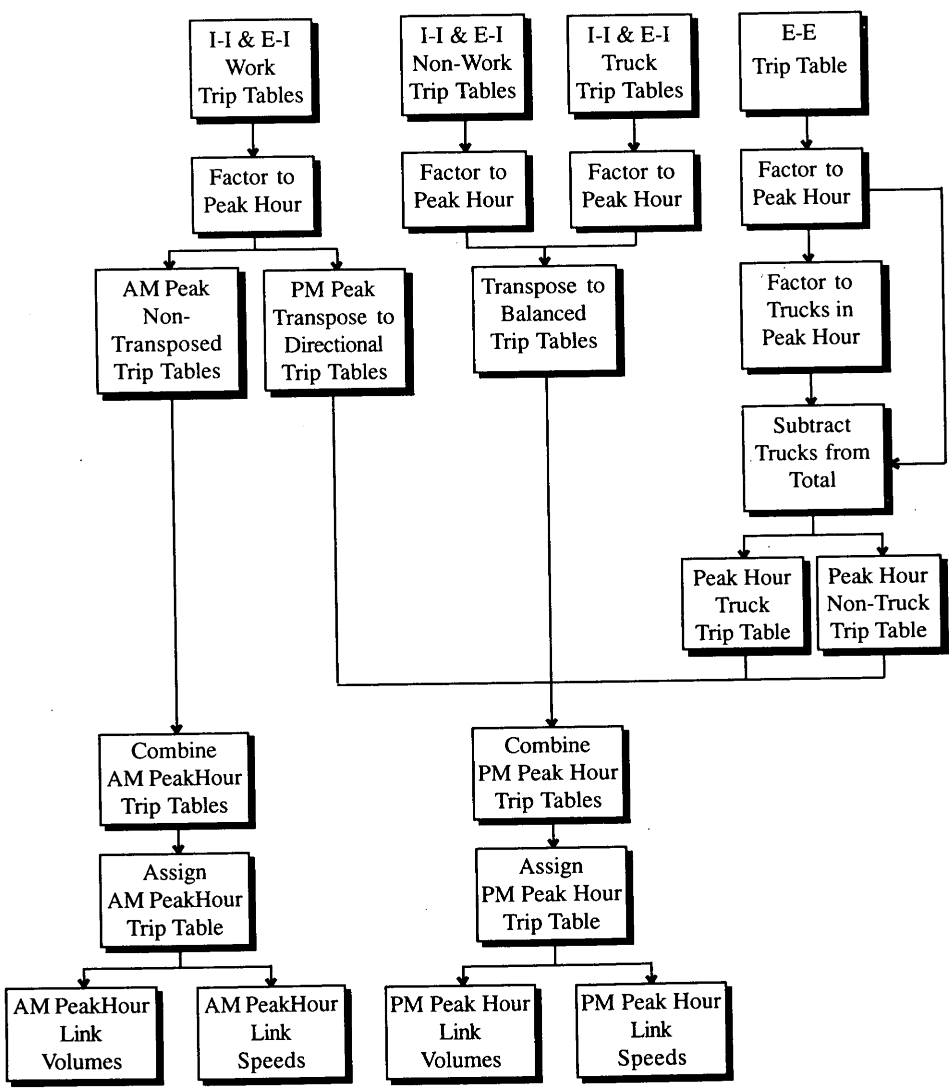

FIGURE 1 Peak-hour conversion process.

in their original form when the trip interchange pairs represent productions and attractions (P&A). A subsequent step in the process transposes the trip tables into an origin and destination (O-D) format that represents a balanced trip table. The primary difference between the P&A and O-D matrices is the recognition of the zone of residence. Thus the P&A table is skewed to an A.M., or morning, peak. To appropriately represent an evening peak the P&A trip table is transposed, or flipped, to skew the trip interchange pairs to the evening peak. This treatment of the I-I and E-I HBW trip tables is considered to more accurately portray the directional aspects of work-oriented travel. Factors are applied to convert the work purposes to the peak hour.

Convert Nonwork Trips to Peak Hour

Following a logic similar to that applied to work trips, the I-I and E-I nonwork trip components of daily travel have peaking characteristics that are unlike work trip components, and therefore the directionality is not as critical. Home-based shopping, other, and school trips generally have patterns that occur throughout the nonpeak hours and can be appropriately described in the balanced O-D format. The factors for these purposes are applied to the nonwork trip tables generated by the distribution model and balanced by normal procedures.

Convert Truck Trips to Peak Hour

Two components of truck travel are addressed separately:

- I-I Trucks. The movement of internal truck traffic is consistent with the concept of balanced morning and evening peak travel. The factors developed for truck travel described earlier are applied to the trip table transposed into the balanced O-D format.
- E-I Trucks. The movement of trucks into and out of the study area is also considered to be balanced. The key difference is in the factor to be applied to represent the evening peak.

Convert External Travel to Peak Hour

The final component of the travel demand model that requires conversion is the E-E component, or through travel. Traffic count data are available for each external station in the NCC modeling system. Factors were developed for each external to establish two characteristics:

- Peak hour as a percentage of AADT.
- Trucks as a percentage of peak hour.

The factors were applied by using the Fratar technique to model the external stations and establish peak-hour values. The second step was to create a trip table for trucks by applying the truck percentages to the peak-hour trip table, also through the use of Fratar. Finally the peak-hour truck trip table is subtracted from the total-peak-hour trip table to create a peak-hour nontruck trip table. The separation of trucks at this point allows the user to combine the I-I, E-I, and E-E truck trip tables if a special analysis is required or desired for emissions calculations.

Peak-Hour Factors

To make hourly and seasonal estimates possible, significant traffic count data are needed in addition to the 24-hr travel demand estimates. The technique relies on the availability of hourly counts from permanent count stations and classification data to establish hourly volumes as a percentage of daily travel. The classification counts provide estimates of truck and non-truck data. The following kinds of data are available from DelDOT for NCC:

- Permanent Count Stations. There are 20 stations in NCC at which 24-hr counts are recorded hourly for 365 days each year. The data from each of these locations were arrayed to calculate hourly percentages. Directionality was also maintained in the process to identify directional splits. The resulting information formed the base for identifying the evening peak hours and the percentage of the total 24-hr count of each one.
- Traffic Count Stations. Shorter-term counts are taken at various locations throughout NCC and are expanded to an AADT volume. The report in which these counts are summarized by maintenance road section also includes peak-hour and truck percentage information.

The peaking characteristics of traffic on a regional basis tend to remain consistent over time, and the peak-hour data used in this process can be assumed to remain valid for forecast years. However the peak-hour percentages should be evaluated for applicability to forecast years, particularly if major land use changes are anticipated to occur, as evidenced by the allocation of population or employment growth in certain traffic analysis zones.

Peak-hour truck travel percentages for I-I and E-I movements were borrowed from an FHWA report (*1*). Of the data provided, Louisville, Ky., appeared to be an area most comparable to NCC. Figure 2 presents the percentages of internal and external truck travel by hour of day. Since the application of these data DelDOT has translated its traffic count data into a geographic information system, which will expedite access to time-of-day data for trucks and nontrucks for future efforts.

Information regarding the percentage of travel by purpose during the peak hour is also required for nontruck travel. Because the travel demand models were developed in the mid-1960s in most states, the source data from the household surveys were aggregated to zonal averages and the original detail was lost. Therefore a reconstruction of travel characteristics was not possible. This situation required that a more current source of time-of-day travel data by purpose be identified, evaluated, and applied. One reliable source of current information is the Nationwide Personal Transportation Survey (NPTS). The percentage of travel by purpose [work, shop, other, non-home-based (NHB)] can be estimated from these data. For this effort a special tabulation was generated to create a matrix of trips by purpose and hour of day. Because of the survey's sample size the information could not be focused on Delaware specifically. The most statistically reliable level available was for the South Atlantic Region, which covers the area along the East Coast from Delaware to Florida.

To convert the 24-hr NCC travel demand model to represent peak-hour travel, a series of factors had to be developed. The nontruck I-I and E-I purposes were factored with values derived from NPTS. These distributions are represented graphically in Figure 3. It would have been more desirable to have such information in smaller time increments, such as 15-min slices, to more

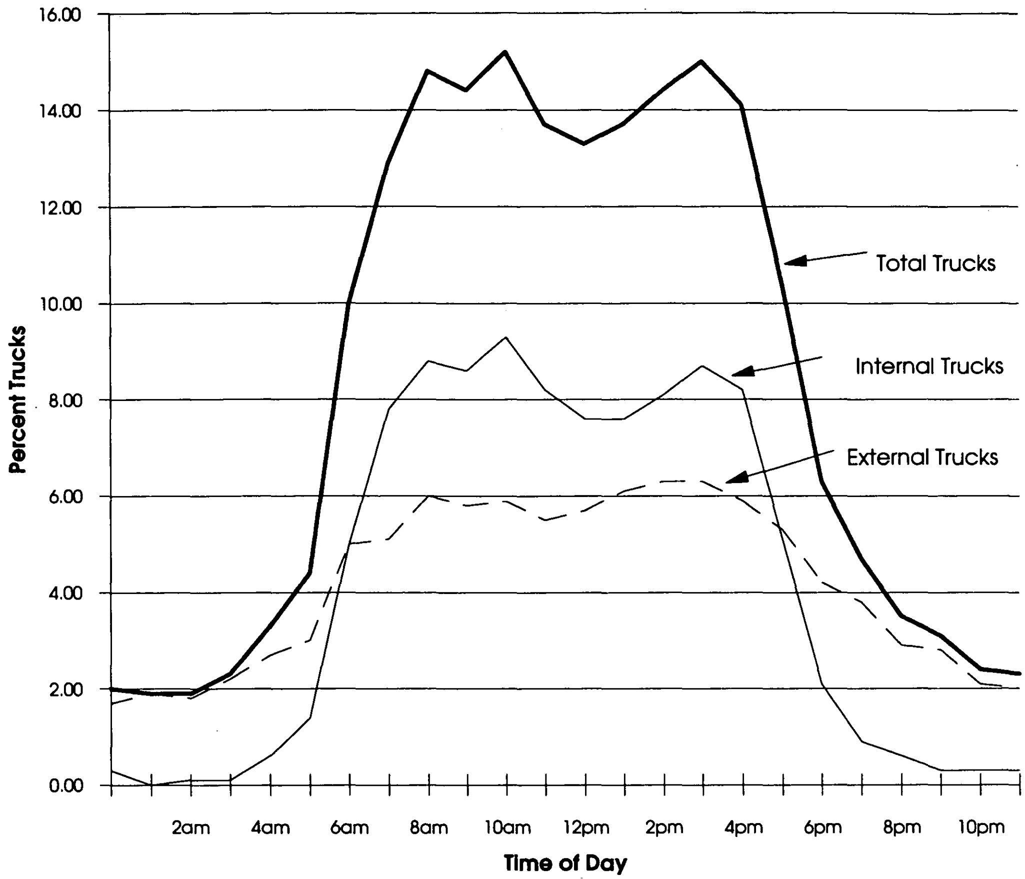

FIGURE 2 Hourly distribution of truck travel (*1*).

accurately evaluate peak-period spreads. Although the data might indicate a peak hour from 4:00 to 5:00 p.m., it might actually be 4:15 to 5:15 p.m. Because the DelDOT traffic counts and the NPTS data are reported in hourly increments, an inspection of the peak-hour percentages for the 20 permanent count stations in NCC suggested evening peak hours of 4:00 to 5:00 and 5:00 to 6:00 p.m. A similar review of the NPTS data also showed evening peaks of 4:00 to 5:00 and 5:00 to 6:00 p.m. Therefore the percent breakdowns for trip purposes according to NPTS were applied to the NCC data as shown in Table 3.

The identification of hourly travel percentages for external stations was accomplished by processing of permanent traffic count data in NCC. Data from selected stations were summarized to establish the 24-hr increments as a percentage of the total. When regional travel demand models are developed, the travel inventory usually records data for travel on nonholiday weekdays, and the resulting trip generation relationships represent average weekday traffic (AWDT). To obtain an estimate of travel that was as accurate as possible for application to emissions modeling, AWDT counts were obtained by deleting weekend days and major holidays from the permanent count station data. Peak-hour percentage factors were developed from the traffic count data for each of the external stations.

INTRAZONAL VMT ESTIMATES

Because intrazonal trips are not loaded onto the network, estimates of travel, or in this case VMT, are underestimated. Furthermore for emissions calculations intrazonal trips are usually made at speeds lower than the speeds that trips on the rest of the system are made, thereby probably creating a relatively greater volume of pollutants.

The options for estimating intrazonal VMT are somewhat limited. Because the effort to derive link VMT and speeds had a practical orientation, available resources were used. NCC tree building and skimming were accomplished with DelDOT's software of choice, which has an option that allows the user to estimate intrazonal travel times by averaging the travel times to adjacent zones. This approach generally recognizes the size of the zone and results in a reasonable approximation of the intrazonal travel times.

For the NCC system an average intrazonal travel speed of 15 mph was used. Given the time value of intrazonal travel and an average intrazonal speed the distance was easily calculated.

When the intrazonal travel distances are calculated they are arrayed as the diagonal cells of a to-from matrix. Likewise the intrazonal volumes in a trip table are represented in a similar diagonal. To obtain a total intrazonal VMT estimate the values in the diagonals of the distance matrix and the factored trip tables for each purpose are multiplied and summed. Figure 4 graphically represents the process for estimating intrazonal VMT.

ASSIGNMENT PROCEDURE

The final step in estimating peak-hour travel is to combine each of the factored purposes and movements into one trip table for

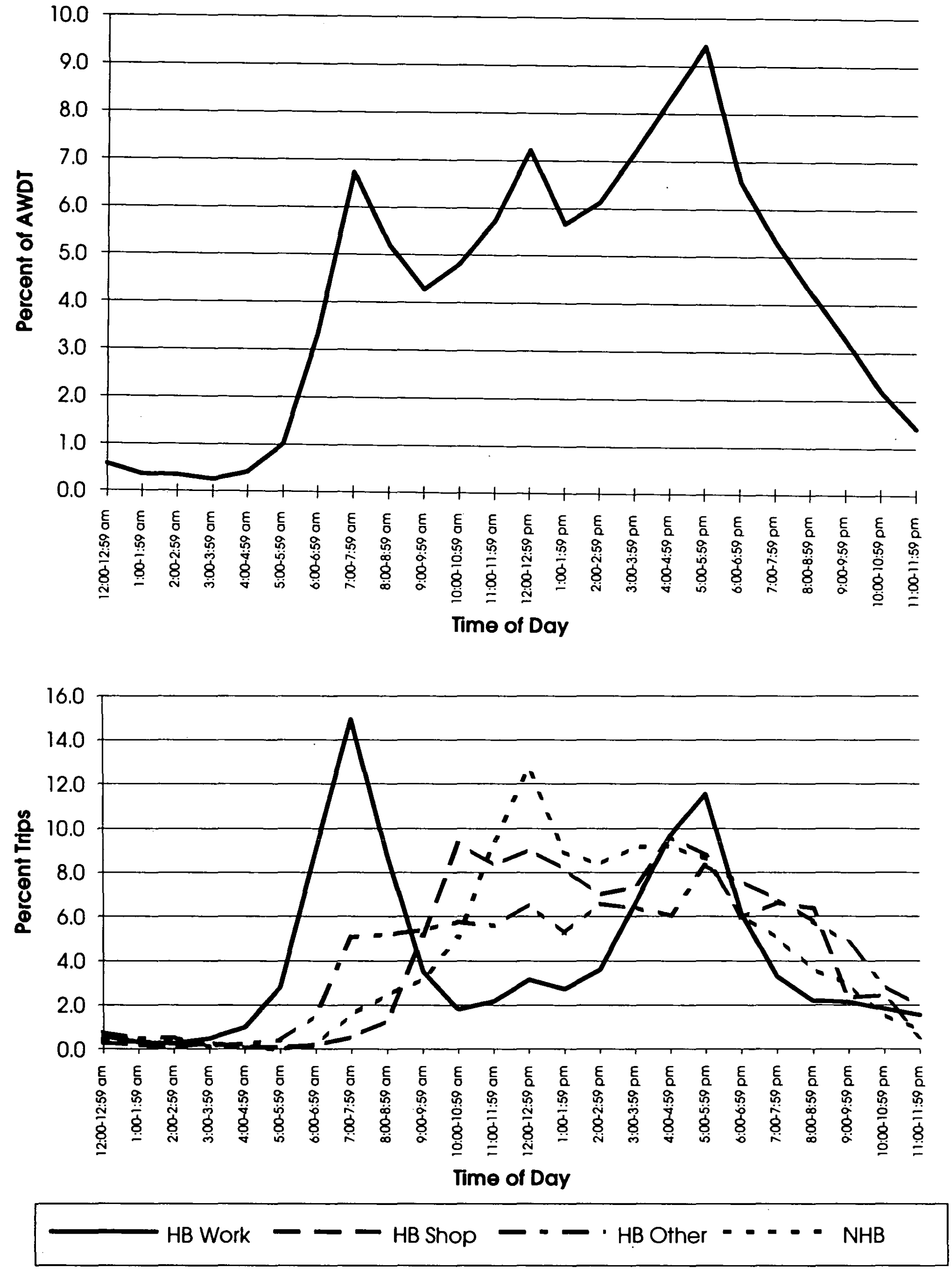

FIGURE 3 NPTS data for total trips (*top*) and trips by purpose (*bottom*).

use in the assignment process. For NCC the equilibrium technique was used, with the assigned volumes restrained by the hourly capacities represented on each of the network links. Speeds were also saved to provide the user with the volumes and speeds for each link in the network that are received to calculate emissions on a link-by-link basis.

Because emissions estimates were required for a peak 120-min period and because the assignment technique uses capacity as a restraint, two peak-period hours were selected and separate assignments were executed. The emissions were then calculated individually for each hour and were combined for the total peak period.

At the time of the effort described here the base traffic count data in Delaware were recorded in hourly increments, and the hour was the smallest time unit that could be applied. Some data bases might be available in 15-min increments, thereby providing the user with more flexibility in defining the peak period.

TABLE 3 Peak-Hour Factors (*1*)

Movement	Purpose	NPTS - PH Factors[1] (%) 4-5 P.M.	5-6 P.M.
I-I	HB Work	9.7	11.5
	HB Shop	9.6	8.8
	HB Other	6.1	8.3
	NHB	9.2	8.6
	HB School	0.1[2]	0.1[2]
E-I	Work	9.7	11.5
	Shop	9.6	8.8
	Other	6.1	8.3
I-I	Trucks	8.2[3]	5.1[3]
E-I	Trucks	5.9[3]	5.3[3]
E-E	Trucks	Variable[4]	Variable[4]
	Non-Trucks	Variable[4]	Variable[4]

Notes:

1. Source: NPTS, South Atlantic Region. These values represent the percent of 24-hour travel for the purpose and hours shown.
2. A nominal value was assigned to school trips (HBSc) expected to occur during the evening peak period.
3. A 1972 report by FHWA (Analysis of Urban Area Travel by Time of Day, FM-11-7519) reported general information for Louisville, KY (determined to be comparable in character to NCC) internal and external truck travel.
4. Truck and non-truck PH percentages were obtained for each external station from the Department's 1990 Traffic Summary Report.

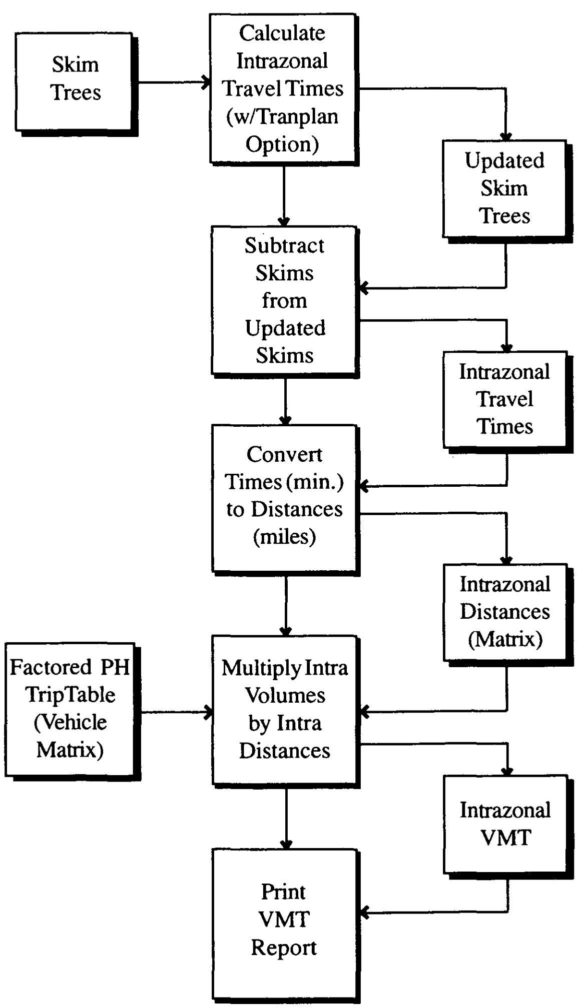

FIGURE 4 Intrazonal VMT estimate process.

CONCLUSIONS

The derivation of peak-hour travel volumes for the calculation of vehicle emissions in urban, regional, or statewide study areas requires innovative and creative techniques because of the absence of available data and procedures developed for that specific purpose. Most existing travel demand models offer a viable data base that, when combined with a comprehensive traffic counting program and travel data from other sources, can be factored and manipulated to provide reasonable estimates of hourly volumes and speeds for any hour of the day and for any day of the year. These features enable the user to examine morning, midday, or evening peak hours or periods for any seasonal needs and offers a practical and credible approach to adapting the travel demand models to peak-hour data.

The process provides more flexibility by allowing the user to separate truck travel in calculations of vehicle emissions in contrast to the flexibilities of other broader methods, such as across-the-board peak-hour factoring or application of peak-hour factors by route type. The example used in this paper is specific to NCC in Delaware. The procedure can be applied for most model structures to represent the variety of temporal conditions required to prepare a mobile on-road emissions inventory. Estimates of emissions, and particularly reductions in emissions owing to improved transportation system components for future transportation system scenarios, will depend on application of the same procedures and factors described above. As with most modeling techniques base year relationships are assumed to carry forward to the future. With the types of data used to factor the 24-hr models by the procedure described here, there is an opportunity to review trends over time and make adjustments as necessary.

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1. *Analysis of Urban Area Travel by Time of Day*, Table I-6. Report FM-11-7519. FHWA, U.S. Department of Transportation, 1972.

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