Start Modes of Trips for Mobile Source Emissions Modeling

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An important determinant of vehicle emissions during a trip is the engine temperature at trip start. A trip start may be classified as a cold start or a hot start depending on the emission control equipment and the duration of engine shut-off period before starting the engine. Cold starts are usually associated with higher concentrations of carbon monoxide and hydrocarbons than are hot starts. The emission modeling process uses these start modes as direct or indirect inputs to procedures or models that would be used to determine the portion of vehicle miles traveled in transient and stabilized operating modes. A methodology for determining the operating mode fractions at trip ends is shown. Specifically, a comprehensive analysis of personal travel data available in Nationwide Passenger Transportation Survey data is performed for deriving start mode fractions at trip origins and operating mode fractions at trip destination points. Start mode fractions as cold starts and hot starts are derived for different trip purposes and for each hour of the day. It was observed that the trip purpose is the most important explanatory variable for variance in cold starts, followed by the temporal variables such as the time of day at which the trip is made. The sizes of an urban area and individual metropolitan statistical areas are found to be the two most appropriate spatial variables for which aggregated start mode percentages may be derived. The start mode fractions derived from this methodology will be useful for a variety of mobile source emission modeling exercises.

The Clean Air Act of 1970 (CAA) mandates that mobile source emission inventories be prepared as an integral part of state implementation plans (SIP). The CAA Amendments of 1990 (CAAA) require that all major transportation improvement projects be analyzed for air-quality–related impacts. To comply with these regulations, most mobile source emission modeling is performed using either the Environmental Protection Agency's (EPAs) MOBILE model or California's EMFAC. For the MOBILE model, the start mode of a trip is not required to be specified as input; however, the fraction of the vehicle miles of travel (VMT) in cold and hot transient modes must be specified. For the EMFAC model and any procedure based on the modal approach, start modes must be specified explicitly.

In this context, it is important to differentiate the start mode at trip origin from the operating mode during the trip. In this paper, the operating mode at the start of a trip is referred to as either a cold start or a hot start. The operating mode during or at the end of a trip is referred to as either a cold transient, hot transient, or hot stabilized. The EPA historically has defined a cold start as any start that occurs 4 hrs or later following the end of the preceding trip for noncatalyst-equipped vehicles and 1 hr or later following the end of the preceding trip for catalyst-equipped vehicles. Hot starts are those starts that occur less than 4 hrs after the end of the preceding trip for noncatalyst vehicles and less than 1 hr after the end of preceding trip for catalyst-equipped vehicles (*1*). The duration associated with restarting the engine after the end of the preceding trip is called a cold-soak or simply the soak period.

Before attaining the hot stabilized operating mode during which the rate of emissions is significantly lower, a vehicle will be operating in either a cold transient mode (for a cold start) or a hot transient mode (for a hot start). The duration of each of the two transient modes is specified as 505 sec in the Federal Test Procedure (FTP), which is used to test the new vehicles for compliance with EPA emission standards. If the proportion of trips starting in cold and hot modes is known, it is possible to trace these cold start and hot start trips along potential routes taken on the network. The purpose of such analysis using a number of transportation modeling techniques is to derive the VMT-weighted proportions of transient and stabilized modes needed to determine average emission rates (*2*).

The start mode at the beginning of each trip is determined by the duration of the cold soak period and the vehicle type. To derive these start modes at trip origins, data pertaining to cold soak period and vehicle type are needed. Origin-destination data collected for comprehensive urban transportation planning purposes usually contain this information. However, these data sources are localized, tend to be outdated, and are sometimes inadequate for determining start modes. A comprehensive data base on personal travel, Nationwide Personal Transportation Survey (NPTS), available for public use through the U.S. Department of Transportation (USDOT) was examined for this purpose. This paper discusses the analysis of the NPTS data base for deriving start modes at trip origins. Following this introductory section, the state of the art is reviewed. In the remainder of the paper, the analysis of NPTS data base is discussed, followed by a detailed discussion on the start modes by time of day and trip purpose.

STATE OF THE ART

The MOBILE model (version 5A) recommends the use of default operating mode fractions at 20.6 percent cold transient and 27.3 percent hot transient modes. These values are based on the FTP drive cycle and do not consider possible variations due to several factors, such as functional class of a roadway facility, geographic location, and start modes at trip origins. For SIP-related modeling, EPA accepts the use of FTP operating mode fractions, except for small-scale scenarios where their use would clearly be inappropriate (*1*). These operating mode fractions were derived on the basis of the start mode fractions that represented conditions of a typical urban setting (such as Los Angeles) and do not represent variable urban settings (*3*).

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One way to resolve the limitations associated with FTP operating mode mix is to use field observations and measurements. An accurate determination of the operating mode of a vehicle engine requires measurements of the engine temperature, and such measurements are difficult to implement on a vehicle while operating under normal traffic conditions.

Only a few studies attempted to determine operating modes of vehicles traveling on regular roads by field measurements. These include a study in New Jersey (*4*). Data representing six functional roadway classifications were collected at field sites. With the permission of the drivers, engine oil and coolant temperature were measured, and engine run time estimates were obtained from the driver. The collected data were analyzed for determining percentages of hot transient, cold transient, and hot stabilized modes of operation in the traffic.

There is an indirect approach of estimating the operating modes of vehicles traveling on a roadway. This approach uses the travel time from a trip origin as an indicator of the operating mode. The travel time from trip origin can be estimated either by interviewing drivers (as in the case of New Jersey study) or by modeling. The interview technique is expensive and difficult to implement. Therefore, the modeling approach is more feasible.

Venigalla (*2*) and COMSIS (*5*) have developed algorithms to trace transient mode trips on network links. The Traffic Assignment Program for Emission Studies (TAPES) (*2*) and the ASSIGN module in the latest version of MINUTP (*5*) use these algorithms. These models require the analyst to provide data on engine start modes by trip purpose. The portions of cold or hot starts at the beginning of trips will affect the proportions of cold and hot transient modes as well as the hot stabilized modes on various facilities.

Therefore, one of the most important inputs to deriving operating mode fractions using the modeling approach is the start mode fractions at trip origins. Ellis et al. (*6*) have analyzed origin-destination survey data for six Alabama urban areas (Birmingham, Mobile, Huntsville, Montgomery, Tuscaloosa, and Etowah) and Boston, Massachusetts. The study analyzed the beginning and ending times of each vehicle trip and the purpose of the trip. The percentages of cold starts were tabulated for catalyst-equipped vehicles by trip purpose (Table 1) for the six cities in Alabama.

Another study by Garmen Associates attempted to derive the percentage of cold starts to be used as input for assignment models (*2*). The study was aimed at analyzing cold starts VMT for south and north Jersey planning areas in New Jersey. Table 1 also lists the cold start vehicle trip percentages used by this study for north and south Jersey study areas. The study referred to the MOBILE model user's guide and a few test runs as the source of these numbers. However, the study made strong assumptions related to cold starts by trip purpose. For example, it was assumed that work trips are almost always cold start trips, because the car usually sits for hours in the driver's driveway at home or the parking lot at work, whereas shopping and non–home-based (NHB) trips are likely to be hot starts.

It can be seen that there is considerable variation in the numbers derived or used by different studies for cold start proportions. These numbers are either old or derived based on a number of crude assumptions. It is obvious that these percentages significantly influence the operating mode fractions on different facilities. Erroneous operating mode fractions will result in wrong emission factors. Thus, any error in the assumptions made with regard to start modes would carry all the way over to the stage where emissions are estimated.

TABLE 1 Percentage of Cold Starts Used for Different Studies

Trip Purpose	Percent Cold Starts Used for:					
	Alabama/Boston (1978)		New Jersey[1](1992)		Washington DC (1991)	
	Catalyst	Non-Catalyst	South Jersey	North Jersey	Catalyst	Non-Catalyst
Work	92.3	81.5	90	90	93.7	82.6
Personal Business	52.9	30.3	NI	NI	NI	NI
Social/Recreational	71.6	25.6	NI	NI	NI	NI
School	86.1	63.2	NI	NI	NI	NI
Shop	86.1	23.6	NI	45	NI	NI
Non-Home Based	37.0	14.8	NI	40	NI	NI
Casino Work	NA	NA	90	NA	NI	NI
Casino Visit	NA	NA	75	NA	NI	NI
Beach	NA	NA	85	NA	NI	NI
Other	NI	NI	50	50	66.4	37.0
I/X	NI	NI	0	70	NI	NI
X/I	NI	NI	0	0	NI	NI
X/X	NI	NI	0	0	NI	NI
Average Weighted	*61.5 (Alabama) 56.4 (Boston)*	*40.3 (Alabama) 34.9 (Boston)*	*57*	*59*	*74.1 (Total Daily)*	*49.9 (Total Daily)*
Note:	NA - Not Applicable; NI - Not Indicated; I/X - Internal to External Trips; and X/I - External to Internal Trips [1] Type of emission control equipment was not indicated for the New Jersey Study.					

PREPARATION OF NPTS DATA

NPTS periodically compiles national data on the nature and characteristics of personal travel. It addresses a broad range of travel in the United States providing data on all personal trips for all purposes and by all modes of transportation (*7*). No information on the trips of commercial nature, such as pickup and delivery trips, is available in this data base.

The 1990 NPTS data base includes information on 41,178 vehicles used for 149,546 trips made in a 24-hr travel day. Consult USDOT'S user guide for NPTS data tapes (*7*) for further details on the data base.

The analysis of this data base for determining the operating modes at trip ends was performed in a number of steps while exercising caution at each step with regard to data on questionable trip and vehicle records. The process involved the following distinctive steps:

1. Identify relevant variables in the NPTS data base.
2. Identify vehicles with catalytic converters.
3. Determine cold soak period for each trip.
4. Associate each trip end with an operating mode on the basis of individual mode and trip duration.
5. Perform an analysis for trip duration, operating modes at trip ends, and percentage of vehicle miles of travel in different operating modes.

Relevant variables extracted from the vehicle and day trip files of the data base include the following:

- Household identification number;
- Vehicle identification number;
- Make year of the vehicle;
- Census region, census division, metropolitan statistical area (MSA) variables, and size of urban area;
- Start time and length of each trip in minutes and miles; and
- Trip purpose variables.

Information on emission control equipment mounted on each vehicle is not present in the data base. For this reason, a methodology was devised to identify the emission control equipment on the basis of available information. This methodology assumes that all vehicles manufactured after 1975 are mounted with catalyst converters so that the EPA's emission standards could be met (*2*). Also, it was assumed that about 25 percent of the vehicles manufactured

and sold before 1975 were equipped with the converters as a result of lack of sufficient information. Because the total number of vehicles with model year before 1975 was less than 8 percent of the total vehicles (41,178) in the data base, any errors occurring in the overall analysis because of this assumption are minimal. This procedure identifies 2,191 (5.3 percent) vehicles in the data base as noncatalyst equipped and 38,987 (94.7 percent) vehicles as catalyst equipped.

The data base was rearranged so the chain of trips made by each vehicle can be identified individually. The cold soak period between two successive trips was computed by using the data on begin time and duration of each trip. After the emission control equipment of each vehicle and cold soak period of each vehicle trip are determined, each trip start was identified as a cold start or hot start based on the standard definitions mentioned in the introduction section of this paper.

The trip chains used for final analysis were subjected to a series of consistency checks. Questionable trip chains due to insufficient information were discarded. The data screening process reduced the eligible data base size from 149,546 to 105,903 trips. After final screening, the data base was found to adequately represent the sampling characteristics of the original data base.

ANALYSIS FOR START AND OPERATING MODES AT TRIP ENDS

Frequencies were obtained, by trip purpose and hour of day, for cold start, hot start, cold and hot transient, and stabilized modes at the origin and destination points of trips. The analyses were conducted for all trips in the data base, which means that the results should represent nationwide average values. In Table 2, the percentages of cold and hot start modes as well as the frequencies by hour of day and trip purpose are presented. The start modes and the operating modes at the ends of trips for all trip purposes can be derived from Table 2. The operating mode percentages—cold and hot transient modes and hot stabilized modes—at the ends of the trips are presented in Table 3.

The figures presented in Tables 2 and 3 are national averages and do not represent any geographic detail. These figures, in general, indicate that more trips in the morning hours are in a cold start mode. The percentage of trips starting in cold mode falls as the day progresses, a trend that would be expected. On the other hand, most trips appear to be ending in a hot stabilized mode, which also conforms to intuition on travel patterns in general. The numbers presented in Tables 2 are plotted in Figure 1 which indicates the following:

- As expected, most of the home-based work (HBW) trips or home-based other (HBO) trips made in the morning hours (between 3:00 a.m. and 10:00 a.m.) started in a cold mode. As the day progresses, the share of cold starts is reduced.
- On the other hand, for NHB trips between the hours of 6:00 a.m. and 10:00 a.m. more than 60 percent of the trip starts were in the hot start mode. Most of the NHB trips made during this time would perhaps be to leave for work either after stopping for breakfast or after leaving children at schools or daycare centers. Trips of this nature indicate a cold soak period of 0 min to less than 1 hr, indicating the engine start in a hot mode.
- The percentage of hot starts for home-based trips reach a peak during the afternoon hours (2:00 p.m. to 6:00 p.m.).
- The percentage of cold starts for all trip purposes indicates a peaking of cold starts between 4:00 a.m. and 7:00 a.m. Conversely, the percentage of hot starts will be the lowest during this period.

TABLE 2 Start Modes at Trip Origins by Time of Day

Time Period	Percent HBW Trips in: Cold Start	Percent HBW Trips in: Hot Start	Percent HBO Trips in: Cold Start	Percent HBO Trips in: Hot Start	Percent NHB Trips in: Cold Start	Percent NHB Trips in: Hot Start
12 AM to 1 AM	87.2 (170)	12.8 (25)	70.5 (244)	29.5 (102)	72.4 (84)	27.6 (32)
1 AM to 2 AM	85.4 (88)	14.6 (15)	70.5 (141)	29.5 (59)	73.2 (41)	26.8 (15)
2 AM to 3 AM	93.0 (80)	7.0 (6)	72.0 (85)	28.0 (33)	77.6 (38)	22.4 (11)
3 AM to 4 AM	91.2 (93)	8.8 (9)	64.2 (43)	35.8 (24)	77.3 (17)	22.7 (5)
4 AM to 5 AM	93.3 (208)	6.7 (15)	85.0 (51)	15.0 (9)	80.0 (12)	20.0 (3)
5 AM to 6 AM	93.6 (703)	6.4 (48)	79.9 (119)	20.1 (30)	52.6 (10)	47.4 (9)
6 AM to 7 AM	91.9 (2049)	8.1 (181)	72.9 (415)	27.1 (154)	25.3 (20)	74.7 (59)
7 AM to 8 AM	86.4 (3119)	13.6 (493)	63.8 (1422)	36.2 (807)	21.8 (70)	78.2 (251)
8 AM to 9 AM	80.4 (1666)	19.6 (406)	59.0 (1639)	41.0 (1140)	21.5 (122)	78.5 (445)
9 AM to 10 AM	78.5 (672)	21.5 (184)	60.8 (1887)	39.2 (1219)	27.4 (230)	72.6 (609)
10 AM to 11 AM	73.0 (381)	27.0 (141)	60.2 (2075)	39.8 (1369)	29.8 (395)	70.2 (930)
11 AM to 12 PM	67.4 (339)	32.6 (164)	57.5 (1951)	42.5 (1440)	39.5 (766)	60.5 (1174)
12 PM to 1 PM	58.8 (490)	41.2 (343)	53.9 (2109)	46.1 (1804)	43.7 (1165)	56.3 (1500)
1 PM to 2 PM	63.0 (463)	37.0 (272)	53.5 (1888)	46.5 (1640)	40.4 (853)	59.6 (1257)
2 PM to 3 PM	73.6 (706)	26.4 (253)	52.5 (2006)	47.5 (1816)	41.9 (852)	58.1 (1181)
3 PM to 4 PM	77.7 (1437)	22.3 (412)	46.3 (2073)	53.7 (2401)	48.0 (1145)	52.0 (1241)
4 PM to 5 PM	75.4 (1915)	24.6 (625)	45.2 (1933)	54.8 (2346)	49.9 (1180)	50.1 (1185)
5 PM to 6 PM	75.3 (2193)	24.7 (720)	44.1 (2057)	55.9 (2605)	49.8 (1147)	50.2 (1154)
6 PM to 7 PM	73.3 (1136)	26.7 (414)	49.1 (2357)	50.9 (2447)	40.5 (649)	59.5 (953)
7 PM to 8 PM	73.9 (564)	26.1 (199)	50.9 (2182)	49.1 (2101)	40.3 (532)	59.7 (788)
8 PM to 9 PM	78.9 (418)	21.1 (112)	50.3 (1702)	49.7 (1681)	42.3 (376)	57.7 (512)
9 PM to 10 PM	79.3 (414)	20.7 (108)	54.9 (1388)	45.1 (1139)	52.3 (345)	47.7 (315)
10 PM to 11 PM	81.9 (398)	18.1 (88)	60.4 (892)	39.6 (586)	62.8 (199)	37.2 (118)
11 PM to 12 PM	84.9 (338)	15.1 (60)	62.8 (547)	37.2 (324)	65.9 (172)	34.1 (89)
Average Daily	79.1 (20040)	20.9 (5293)	53.4 (31206)	46.6 (27276)	43.0 (10420)	57.0 (13836)

Note: Figures in parentheses are number of trips recorded in each cell

The operating modes at the ends of trips, as shown in Figures 2 and 3, indicate the following:

- In general, a large portion of all trips ended in a hot stabilized state. More than 50 percent of all trips ended in this mode during any time of the day.
- The proportions of operating modes at the ends of trips are different for different trip purposes only in the morning, between 5:00 a.m. and 11:00 a.m. During the remainder of the day, the proportions of operating modes are more or less the same for all trip purposes. This can be expected because the length of a trip, rather than simply the start mode at its origin, will be a major determinant of the operating mode at the end of a trip.
- With the exception of non–home-based trips, transient mode trips (Figure 2) peaked during noon hours. This phenomenon indicates that the trips made between 10:00 a.m. and 1:00 p.m. are relatively shorter in duration, a trend that could be expected.

ANALYSIS OF VARIANCE FOR COLD START PERCENTAGES

It would appear that cold and hot start percentages may vary between geographic regions or urban areas by time of day and by trip purpose. However, it is not known a priori whether the differences in cold and hot start percentages are statistically significant for different geographic regions, times of day, and trip purposes.

TABLE 3 Operating Modes at Ends of Trips

Time Period	Percent HBW Trips in: Cold Trans.	Hot Trans.	Hot Stable	Percent HBO Trips in: Cold Trans.	Hot Trans.	Hot Stable	Percent NHB Trips in: Cold Trans.	Hot Trans.	Hot Stable
12 AM to 1 AM	19.0 (37)	3.6 (7)	77.4 (151)	19.1 (66)	6.1 (21)	74.9 (259)	27.6 (32)	6.0 (7)	66.4 (77)
1 AM to 2 AM	19.4 (20)	4.9 (5)	75.7 (78)	16.0 (32)	5.0 (10)	79.0 (158)	23.2 (13)	14.3 (8)	62.5 (35)
2 AM to 3 AM	27.9 (24)	2.3 (2)	69.8 (60)	27.1 (32)	8.5 (10)	64.4 (76)	22.4 (11)	8.2 (4)	69.4 (34)
3 AM to 4 AM	21.6 (22)	1.0 (1)	77.5 (79)	16.4 (11)	3.0 (2)	80.6 (54)	31.8 (7)	13.6 (3)	54.5 (12)
4 AM to 5 AM	17.5 (39)	0.9 (2)	81.6 (182)	31.7 (19)	3.3 (2)	65.0 (39)	46.7 (7)	. (-)	53.3 (8)
5 AM to 6 AM	15.6 (117)	0.8 (6)	83.6 (628)	23.5 (35)	2.0 (3)	74.5 (111)	10.5 (2)	. (-)	89.5 (17)
6 AM to 7 AM	13.8 (307)	1.1 (24)	85.2 (1899)	31.1 (177)	4.2 (24)	64.7 (368)	7.6 (6)	11.4 (9)	81.0 (64)
7 AM to 8 AM	16.3 (590)	2.2 (81)	81.4 (2941)	27.9 (622)	4.6 (103)	67.5 (1504)	8.4 (27)	12.8 (41)	78.8 (253)
8 AM to 9 AM	20.2 (418)	4.8 (99)	75.0 (1555)	26.6 (739)	8.0 (222)	65.4 (1818)	9.0 (51)	21.0 (119)	70.0 (397)
9 AM to 10 AM	24.2 (207)	6.4 (55)	69.4 (594)	24.5 (762)	10.0 (310)	65.5 (2034)	9.5 (80)	23.0 (193)	67.5 (566)
10 AM to 11 AM	20.3 (106)	10.7 (56)	69.0 (360)	24.0 (823)	10.9 (375)	65.2 (2244)	11.2 (148)	27.0 (358)	61.8 (819)
11 AM to 12 PM	21.3 (107)	14.1 (71)	64.6 (325)	21.2 (720)	11.8 (401)	66.9 (2270)	15.8 (306)	22.0 (426)	62.3 (1208)
12 PM to 1 PM	21.4 (178)	19.1 (159)	59.5 (496)	19.6 (766)	12.1 (475)	68.3 (2672)	19.4 (518)	20.1 (536)	60.5 (1611)
1 PM to 2 PM	22.3 (164)	15.9 (117)	61.8 (454)	18.8 (664)	12.9 (456)	68.3 (2408)	15.1 (318)	21.1 (445)	63.8 (1347)
2 PM to 3 PM	16.9 (162)	8.1 (78)	75.0 (719)	18.4 (702)	12.1 (461)	69.6 (2659)	12.9 (263)	20.0 (406)	67.1 (1364)
3 PM to 4 PM	17.4 (322)	7.4 (136)	75.2 (1391)	15.7 (703)	14.3 (639)	70.0 (3132)	15.9 (379)	15.6 (373)	68.5 (1634)
4 PM to 5 PM	13.6 (346)	8.1 (206)	78.3 (1988)	14.9 (636)	15.7 (670)	69.5 (2973)	15.5 (366)	14.7 (347)	69.9 (1652)
5 PM to 6 PM	14.5 (422)	7.3 (214)	78.2 (2277)	14.5 (675)	14.3 (668)	71.2 (3319)	15.0 (344)	15.1 (347)	70.0 (1610)
6 PM to 7 PM	15.2 (236)	7.7 (120)	77.0 (1194)	17.9 (859)	13.7 (658)	68.4 (3287)	13.0 (208)	17.2 (275)	69.9 (1119)
7 PM to 8 PM	17.3 (132)	9.7 (74)	73.0 (557)	19.1 (819)	13.2 (565)	67.7 (2899)	13.9 (183)	17.1 (226)	69.0 (911)
8 PM to 9 PM	18.3 (97)	5.3 (28)	76.4 (405)	19.5 (658)	12.1 (408)	68.5 (2317)	15.2 (135)	18.8 (167)	66.0 (586)
9 PM to 10 PM	19.9 (104)	5.2 (27)	74.9 (391)	17.1 (431)	12.0 (304)	70.9 (1792)	19.8 (131)	12.6 (83)	67.6 (446)
10 PM to 11 PM	16.0 (78)	5.3 (26)	78.6 (382)	19.6 (289)	10.4 (154)	70.0 (1035)	22.4 (71)	9.8 (31)	67.8 (215)
11 PM to 12 PM	18.1 (72)	2.0 (8)	79.9 (318)	19.3 (168)	7.8 (68)	72.9 (635)	27.6 (72)	10.7 (28)	61.7 (161)
Average Daily	17.0 (4307)	6.3 (1602)	76.7 (19424)	19.5 (11410)	12.0 (7009)	68.5 (40063)	15.2 (3678)	18.3 (4432)	66.5 (16146)

Notes: Figures in parentheses are number of trips recorded in each cell

An analysis of the variance of cold and hot start percentages for different spatial, temporal, and trip purpose classifications would not only assess the statistical significance of such a stratification, but would also lead to a more meaningful cross classification. For example, the start percentages may be derived for each hour of the day for a given urban area. However, these percentages may be statistically similar for several consecutive hours such as morning peak period, night hours, and so forth. To minimize the level of effort required to model mobile source emissions, it is necessary to identify such similarities and combine those levels into one class.

Analysis of Variance for Cold Starts

The percentage of cold starts was used as the response variable to analyze the variance of start modes. Because the percentage of hot starts is related to the percentage of cold starts, the inferences drawn from the analysis of cold start percentages apply to hot starts as well. Three groups of variable categories were included as independent variables in the analysis of variance for cold start percentages. These groups are spatial variables, time-of-day variables, and trip-purpose variables. The spatial resolution in the NPTS data includes the following categories:

- Census region (four levels—Northeast, North Central, South, and West);
- Census division (nine levels—New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, and Pacific);
- Urban area size (six population levels—50,000 to 199,999; 200,000 to 499,999; 500,000 to 999,999; 1,000,000 or more with

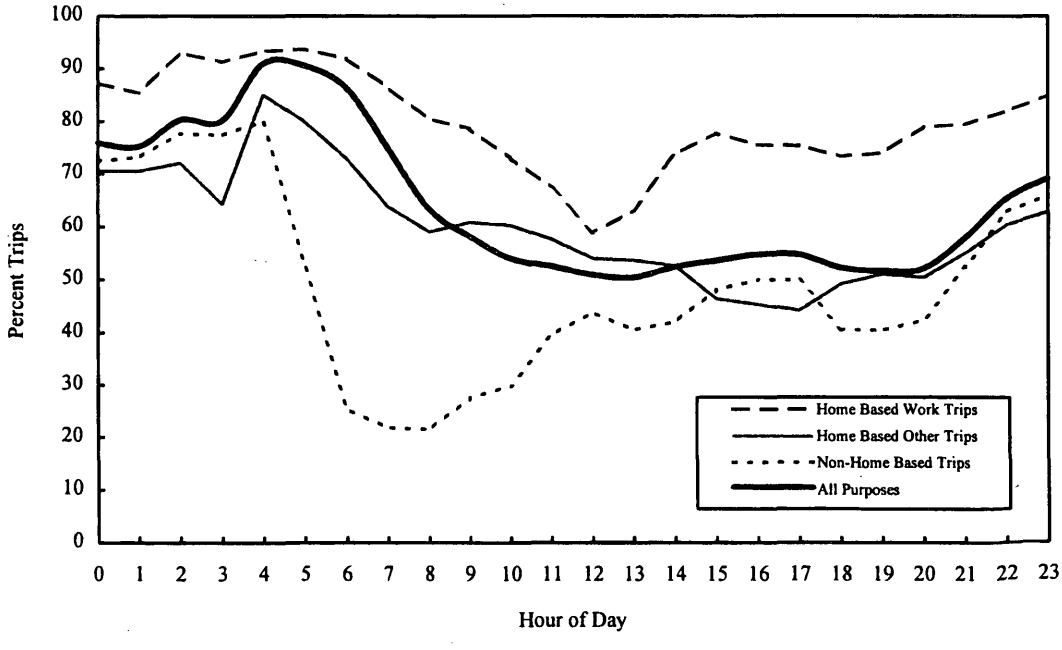

FIGURE 1 Percentage of cold starts by time of day.

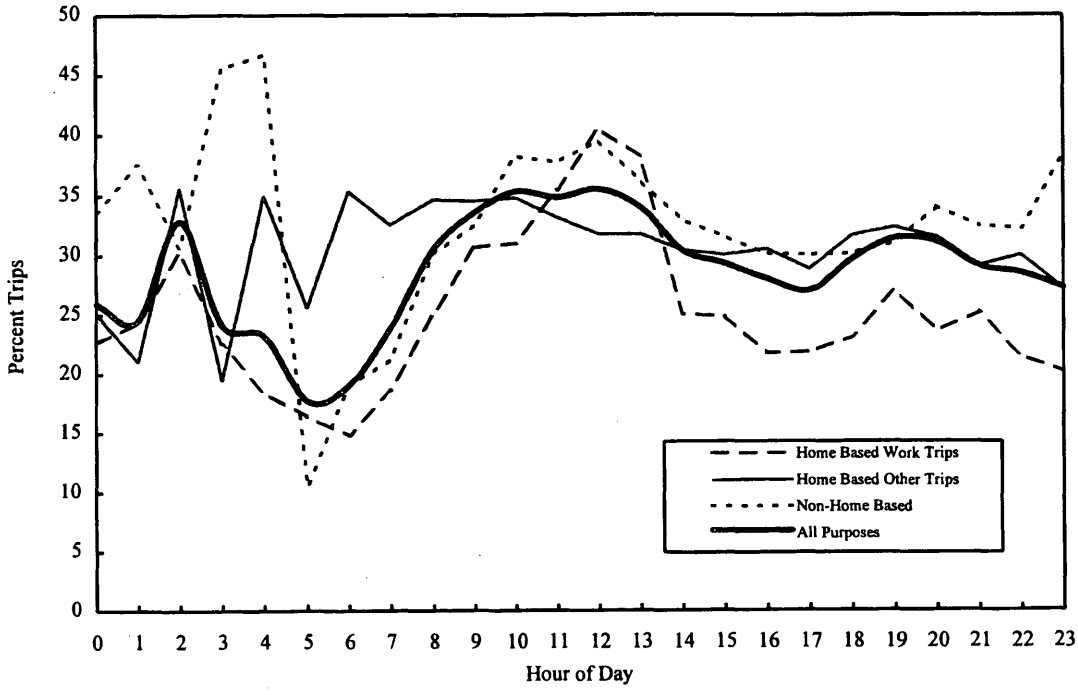

FIGURE 2 Percentage of trips ending in transient mode.

subway/rail; 1,000,000 or more without subway/rail; and not in urbanized area);

- MSA size (six population levels—fewer than 250,000; 250,000 to 499,999; 500,000 to 999,999; 1,000,000 to 2,999,999; 3,000,000 or more; and not in an MSA); and
- Individual MSAs.

All these spatial variables were considered for analysis of variance. Because the time each trip started was recorded in the 24-hr time format, it was possible to derive cold and hot start percentages for each hour of the day. With regard to trip purpose variables, no additional data processing was necessary to identify the purpose of each trip because all the trips in the data base were already identified with a trip purpose. Another variable in the NPTS data base (whytrip) describes the purpose of each trip in further detail than the three variable categories, such as to or from work, school, or church, and pleasure driving. Because trips are often classified as HBW trips, HBO trips, and NHB trips for transportation planning studies,

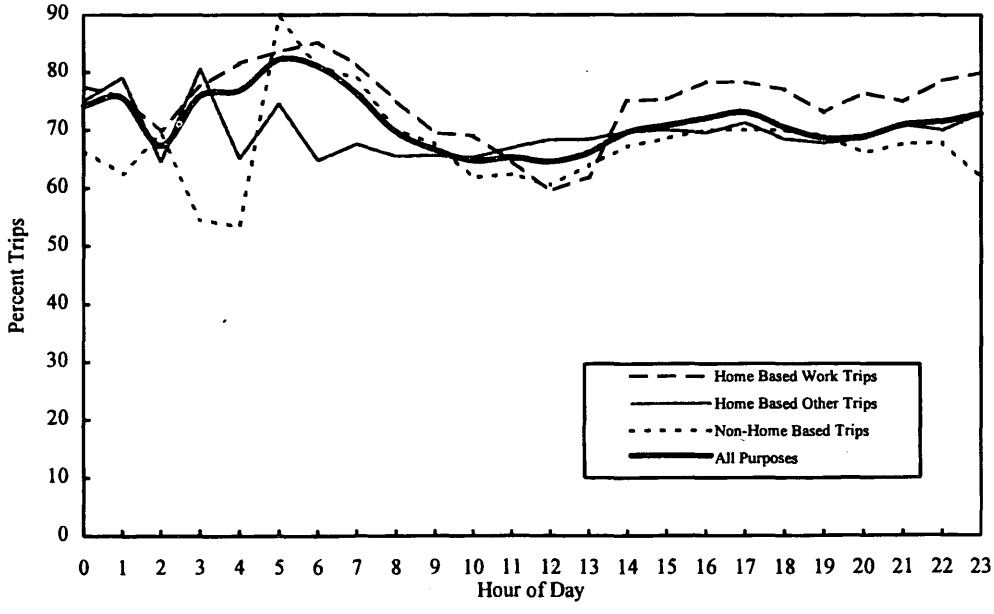

FIGURE 3 Percentage of trips ending in hot stabilized mode.

only the previously mentioned three trip categories were considered for this analysis. Home-based shopping, social/recreational, and other trips were grouped as HBO trips.

Thus, from the NPTS data, cold and hot start percentages may be computed across several levels of spatial, temporal, and trip-purpose variables. There will be only one value for the response variable Y_{ijk} in each cell *ijk*, which is the percentage of cold starts. Because the response variable is a proportion, it is necessary to transform the dependent variable to stabilize the variance. An appropriate transformation for this case is the arc sine transformation, which is performed as follows (*8*):

$$Y' = 2 \arcsin \sqrt{Y}$$

Thus, the final analysis of the variance on the percentage of cold starts was conducted using the general linear model procedure, and the results are summarized in Table 4. The model included the main effects of the three independent variables and only two-way interactions. Because there was only one observation in each cell, no three-way interaction term was specified. In situations like this, the general model uses the three-way interaction term as the error term. The results of the analysis indicate the following:

- Except for the spatial variables, MSA size, and the census division, all other main effects have significant influence on the percentage of cold starts. Therefore, it may be inappropriate to group trips by census division and MSA size for composite values of cold start percentages.
- Trip purpose is the best explanatory variable for variance in the percentage of cold starts.
- The time-of-day variable closely follows the trip-purpose variable as the second most significant main effect.
- The crossed or interaction effects of time-of-day and trip-purpose variables are highly significant. That is, there is a statistically significant reason to believe that the percentage of cold starts does vary by each hour for a given trip purpose.

Even though the census region proved to be a statistically significant main effect, it may not be appropriate to use it to group cold start percentages because this class variable represents a very coarse level of aggregation (four regions for the United States). Individual MSAs, on the other hand, provide a finer resolution for presenting start mode fractions. However, the results can be used only by the MSA in question and may not be transferable to any other MSA. Thus, on a nationwide basis, the most appropriate classification for presenting transferable results is the size of the urban area. The start modes at trip origins were derived for urban areas of different sizes and are presented in Tables 5 to 10.

TABLE 4 Summary Analysis of Variance for Percentage of Cold Starts

Source of Variance	Spatial Variable, *SV*				
	Census Region	Census Division	Urban Area Size	MSA Size	Individual MSA
Model	0.0001 *(10.09)*	0.0001 *(7.97)*	0.0001 *(7.99)*	0.0001 *(6.79)*	0.0001 *(4.17)*
Main Effects					
TP	0.0001 *(249.64)*	0.0001 *(278.48)*	0.0001 *(256.85)*	0.0001 *(197.64)*	0.0001 *(203.31)*
HD	0.0001 *(23.53)*	0.0001 *(44.08)*	0.0001 *(27.59)*	0.0001 *(24.49)*	0.0001 *(48.05)*
SV	0.0246 *(3.22)*	0.2116 *(1.36)**	0.0274 *(2.58)*	0.1452 *(1.66)**	0.0001 *(3.27)*
Interaction Effects					
*SV*TP*	0.6614 *(0.69)**	0.3499 *(1.10)**	0.0442 *(1.92)*	0.1121 *(1.59)**	0.0918 *(1.32)**
*TP*HD*	0.0001 *(7.59)*	0.0001 *(8.99)*	0.0001 *(6.72)*	0.0001 *(5.21)*	0.0001 *(5.44)*
*HD*SV*	0.0310 *(1.46)*	0.1453 *(1.14)*	0.4481 *(1.01)**	0.0937 *(1.23)**	0.0425 *(1.16)*

Notes:
- A separate ANOVA was conducted for each spatial variable.
- The figures indicate the probability of Type I error for each of the effects
- The figures in the parenthesis indicate the F value for the indicated source of variance.
- * indicates that the effect is not significant at α = 5 percent
- *TP* - Trip Purpose
- *HD* - Hour of Day
- *SV* - Spatial Variable (Census Region, Census Division etc)

Procedure for Determining Start Mode Percentages

These findings led to the following recommended procedure for determining the percentages of cold starts:

- Operating modes at trip starts may be derived by time-of-day and trip purpose. When the analysis by trip purpose or time-of-day are unimportant, appropriate composite values for start mode percentages may be derived for all trip purposes for the entire day.
- Whenever possible, the cold and hot start percentages may be derived from the NPTS data for the metropolitan statistical area in question.
- It is possible that for many MSA's there are not enough observations in some of the cells, such as work-related trips at night. When the percentages for some cells are missing and are required for analysis purpose, average trip starts for the urban area size may be derived and substituted for the required trip starts.
- When observations for individual MSAs are inadequate, the start modes derived based on the urban area size (Tables 5 through 10) may be used.

TABLE 5 Operating Modes at Trip Origins (Urban Area Size: 50,000 to 199,999)

Time Period	Percent HBW Trips in		Percent HBO Trips in		Percent NHB Trips in	
	Cold Start	Hot Start	Cold Start	Hot Start	Cold Start	Hot Start
12 AM to 1 AM	93.8 *(15)*	6.3 *(1)*	68.4 *(26)*	31.6 *(12)*	72.7 *(8)*	27.3 *(3)*
1 AM to 2 AM	62.5 *(5)*	37.5 *(3)*	68.8 *(11)*	31.3 *(5)*	50.0 *(2)*	50.0 *(2)*
2 AM to 3 AM	100.0 *(12)*	. *(-)*	66.7 *(8)*	33.3 *(4)*	80.0 *(4)*	20.0 *(1)*
3 AM to 4 AM	94.1 *(16)*	5.9 *(1)*	66.7 *(2)*	33.3 *(1)*	33.3 *(1)*	66.7 *(2)*
4 AM to 5 AM	100.0 *(19)*	. *(-)*	80.0 *(4)*	20.0 *(1)*	. *(-)*	. *(-)*
5 AM to 6 AM	93.4 *(57)*	6.6 *(4)*	85.7 *(6)*	14.3 *(1)*	100.0 *(2)*	. *(-)*
6 AM to 7 AM	90.1 *(182)*	9.9 *(20)*	72.1 *(49)*	27.9 *(19)*	. *(-)*	100.0 *(6)*
7 AM to 8 AM	86.0 *(282)*	14.0 *(46)*	62.9 *(149)*	37.1 *(88)*	18.8 *(9)*	81.3 *(39)*
8 AM to 9 AM	81.4 *(144)*	18.6 *(33)*	60.5 *(173)*	39.5 *(113)*	18.2 *(10)*	81.8 *(45)*
9 AM to 10 AM	83.8 *(67)*	16.3 *(13)*	67.5 *(187)*	32.5 *(90)*	37.2 *(35)*	62.8 *(59)*
10 AM to 11 AM	74.6 *(47)*	25.4 *(16)*	59.8 *(226)*	40.2 *(152)*	23.7 *(31)*	76.3 *(100)*
11 AM to 12 PM	70.3 *(45)*	29.7 *(19)*	54.7 *(222)*	45.3 *(184)*	40.3 *(75)*	59.7 *(111)*
12 PM to 1 PM	63.4 *(59)*	36.6 *(34)*	58.4 *(239)*	41.6 *(170)*	43.0 *(122)*	57.0 *(162)*
1 PM to 2 PM	56.9 *(41)*	43.1 *(31)*	49.4 *(195)*	50.6 *(200)*	43.3 *(97)*	56.7 *(127)*
2 PM to 3 PM	68.0 *(66)*	32.0 *(31)*	50.0 *(211)*	50.0 *(211)*	45.5 *(95)*	54.5 *(114)*
3 PM to 4 PM	77.2 *(156)*	22.8 *(46)*	43.2 *(171)*	56.8 *(225)*	43.0 *(105)*	57.0 *(139)*
4 PM to 5 PM	71.9 *(184)*	28.1 *(72)*	46.1 *(213)*	53.9 *(249)*	49.4 *(118)*	50.6 *(121)*
5 PM to 6 PM	71.2 *(173)*	28.8 *(70)*	43.0 *(203)*	57.0 *(269)*	53.0 *(116)*	47.0 *(103)*
6 PM to 7 PM	69.5 *(89)*	30.5 *(39)*	49.9 *(252)*	50.1 *(253)*	40.2 *(68)*	59.8 *(101)*
7 PM to 8 PM	80.3 *(53)*	19.7 *(13)*	49.9 *(214)*	50.1 *(215)*	41.7 *(53)*	58.3 *(74)*
8 PM to 9 PM	82.1 *(32)*	17.9 *(7)*	51.5 *(176)*	48.5 *(166)*	47.5 *(38)*	52.5 *(42)*
9 PM to 10 PM	77.8 *(42)*	22.2 *(12)*	48.9 *(115)*	51.1 *(120)*	57.4 *(39)*	42.6 *(29)*
10 PM to 11 PM	75.9 *(41)*	24.1 *(13)*	58.6 *(85)*	41.4 *(60)*	51.4 *(18)*	48.6 *(17)*
11 PM to 12 AM	83.7 *(36)*	16.3 *(7)*	64.0 *(55)*	36.0 *(31)*	61.5 *(16)*	38.5 *(10)*
Average Daily	77.8 *(1863)*	22.2 *(531)*	52.9 *(3192)*	47.1 *(2839)*	43.0 *(1062)*	57.0 *(1407)*

Notes: *Figures in parentheses are number of observations in the cell*

TABLE 6 Operating Modes at Trip Origins (Urban Area Size: 200,000 to 499,999)

Time Period	Percent HBW Trips		Percent HBO Trips		Percent NHB Trips	
	Cold Starts	Hot Starts	Cold Starts	Hot Starts	Cold Starts	Hot Starts
12 AM to 1 AM	77.8 (7)	22.2 (2)	76.2 (16)	23.8 (5)	76.9 (10)	23.1 (3)
1 AM to 2 AM	100.0 (6)	. (-)	84.6 (11)	15.4 (2)	50.0 (3)	50.0 (3)
2 AM to 3 AM	100.0 (6)	. (-)	57.1 (4)	42.9 (3)	50.0 (3)	50.0 (3)
3 AM to 4 AM	100.0 (1)	. (-)	55.6 (5)	44.4 (4)	50.0 (1)	50.0 (1)
4 AM to 5 AM	94.1 (16)	5.9 (1)	100.0 (7)	. (-)	50.0 (1)	50.0 (1)
5 AM to 6 AM	89.7 (35)	10.3 (4)	85.7 (6)	14.3 (1)	. (-)	. (-)
6 AM to 7 AM	92.7 (115)	7.3 (9)	72.4 (21)	27.6 (8)	25.0 (2)	75.0 (6)
7 AM to 8 AM	86.0 (191)	14.0 (31)	67.5 (110)	32.5 (53)	13.0 (3)	87.0 (20)
8 AM to 9 AM	80.8 (101)	19.2 (24)	57.8 (96)	42.2 (70)	36.4 (12)	63.6 (21)
9 AM to 10 AM	88.9 (40)	11.1 (5)	54.9 (101)	45.1 (83)	28.3 (13)	71.7 (33)
10 AM to 11 AM	76.3 (29)	23.7 (9)	59.6 (115)	40.4 (78)	42.5 (31)	57.5 (42)
11 AM to 12 PM	65.5 (19)	34.5 (10)	58.7 (108)	41.3 (76)	32.8 (44)	67.2 (90)
12 PM to 1 PM	63.4 (26)	36.6 (15)	51.6 (128)	48.4 (120)	46.8 (65)	53.2 (74)
1 PM to 2 PM	59.5 (22)	40.5 (15)	50.7 (115)	49.3 (112)	37.0 (47)	63.0 (80)
2 PM to 3 PM	78.3 (47)	21.7 (13)	50.6 (129)	49.4 (126)	46.9 (61)	53.1 (69)
3 PM to 4 PM	69.1 (67)	30.9 (30)	52.3 (138)	47.7 (126)	46.5 (72)	53.5 (83)
4 PM to 5 PM	70.4 (107)	29.6 (45)	45.1 (124)	54.9 (151)	39.5 (62)	60.5 (95)
5 PM to 6 PM	75.3 (143)	24.7 (47)	41.3 (109)	58.7 (155)	50.7 (74)	49.3 (72)
6 PM to 7 PM	71.0 (71)	29.0 (29)	50.5 (143)	49.5 (140)	35.0 (35)	65.0 (65)
7 PM to 8 PM	82.9 (29)	17.1 (6)	50.8 (124)	49.2 (120)	30.0 (21)	70.0 (49)
8 PM to 9 PM	74.2 (23)	25.8 (8)	57.9 (114)	42.1 (83)	40.0 (22)	60.0 (33)
9 PM to 10 PM	81.3 (26)	18.8 (6)	59.3 (86)	40.7 (59)	43.6 (17)	56.4 (22)
10 PM to 11 PM	75.8 (25)	24.2 (8)	52.8 (47)	47.2 (42)	50.0 (13)	50.0 (13)
11 PM to 12 AM	88.0 (22)	12.0 (3)	60.7 (34)	39.3 (22)	42.1 (8)	57.9 (11)
Average Daily	78.6 (1174)	21.4 (320)	53.6 (1891)	46.4 (1639)	41.1 (620)	58.9 (889)
Note:	*Figures in parentheses are number of observations in the cell*					

TABLE 7 Operating Modes at Trip Origins (Urban Area Size: 500,000 to 999,999)

Time Period	Percent HBW Trips		Percent HBO Trips		Percent NHB Trips	
	Cold Starts	Hot Starts	Cold Starts	Hot Starts	Cold Starts	Hot Starts
12 AM to 1 AM	80.6 (25)	19.4 (6)	67.4 (29)	32.6 (14)	88.2 (15)	11.8 (2)
1 AM to 2 AM	68.4 (13)	31.6 (6)	70.0 (28)	30.0 (12)	62.5 (5)	37.5 (3)
2 AM to 3 AM	100.0 (9)	. (-)	68.2 (15)	31.8 (7)	83.3 (5)	16.7 (1)
3 AM to 4 AM	91.7 (11)	8.3 (1)	57.1 (4)	42.9 (3)	. (-)	100.0 (1)
4 AM to 5 AM	81.0 (17)	19.0 (4)	90.0 (9)	10.0 (1)	60.0 (3)	40.0 (2)
5 AM to 6 AM	91.9 (57)	8.1 (5)	71.4 (10)	28.6 (4)	. (-)	100.0 (1)
6 AM to 7 AM	94.9 (260)	5.1 (14)	81.1 (43)	18.9 (10)	20.0 (1)	80.0 (4)
7 AM to 8 AM	85.6 (393)	14.4 (66)	65.3 (162)	34.7 (86)	26.2 (11)	73.8 (31)
8 AM to 9 AM	80.4 (193)	19.6 (47)	60.3 (188)	39.7 (124)	22.2 (14)	77.8 (49)
9 AM to 10 AM	80.6 (75)	19.4 (18)	60.3 (226)	39.7 (149)	31.3 (30)	68.8 (66)
10 AM to 11 AM	84.0 (42)	16.0 (8)	61.0 (211)	39.0 (135)	37.8 (48)	62.2 (79)
11 AM to 12 PM	64.9 (37)	35.1 (20)	58.8 (221)	41.2 (155)	42.9 (93)	57.1 (124)
12 PM to 1 PM	61.8 (63)	38.2 (39)	56.1 (242)	43.9 (189)	45.3 (124)	54.7 (150)
1 PM to 2 PM	60.3 (47)	39.7 (31)	55.1 (218)	44.9 (178)	44.0 (107)	56.0 (136)
2 PM to 3 PM	77.6 (76)	22.4 (22)	50.3 (240)	49.7 (237)	35.8 (78)	64.2 (140)
3 PM to 4 PM	79.4 (170)	20.6 (44)	46.6 (221)	53.4 (253)	49.4 (119)	50.6 (122)
4 PM to 5 PM	76.1 (258)	23.9 (81)	44.1 (217)	55.9 (275)	51.4 (144)	48.6 (136)
5 PM to 6 PM	75.4 (258)	24.6 (84)	44.8 (222)	55.2 (274)	48.1 (140)	51.9 (151)
6 PM to 7 PM	74.1 (140)	25.9 (49)	50.8 (271)	49.2 (262)	40.2 (70)	59.8 (104)
7 PM to 8 PM	71.8 (61)	28.2 (24)	51.5 (290)	48.5 (273)	37.0 (57)	63.0 (97)
8 PM to 9 PM	78.7 (48)	21.3 (13)	51.9 (202)	48.1 (187)	45.8 (55)	54.2 (65)
9 PM to 10 PM	85.5 (59)	14.5 (10)	57.3 (168)	42.7 (125)	49.3 (35)	50.7 (36)
10 PM to 11 PM	75.9 (41)	24.1 (13)	71.5 (118)	28.5 (47)	66.7 (20)	33.3 (10)
11 PM to 12 AM	88.9 (48)	11.1 (6)	63.1 (65)	36.9 (38)	79.2 (19)	20.8 (5)
Average Daily	79.7 (2401)	20.3 (611)	54.4 (3620)	45.6 (3038)	44.1 (1193)	55.9 (1515)
Notes:	*Figures in parentheses are number of observations in the cell*					

- When none of these analyses is feasible, nationwide averages in Table 2 may be used for the time period in question.

The use of these tables is illustrated by deriving operating modes at trip origins for Charlotte, North Carolina, for a morning peak period (7:00 a.m. to 9:00 a.m.) and a 24-hr period. Because the city has a population of about 500,000 in the urbanized area, it is appropriate to use the figures presented in Table 7.

HBW Trips

–Number. of cold start trips between 7:00 a.m. and 9:00 a.m.: 393 + 193 = 586
–Number. of hot start trips between 7:00 a.m. and 9:00 a.m.: 66 + 47 = 113
–Total number of trips between 7:00 a.m. and 9:00 a.m.: 586 + 113 = 699
–Percentage of cold starts between 7:00 a.m. and 9:00 a.m.: 100(586/699) = 83.8
–Percentage of hot starts between 7:00 a.m. and 9:00 a.m.: 100(113/699) = 16.2
–Percentage of cold starts for the 24-hr period: 79.7
–Percentage of hot starts for the 24-hr period: 20.3

HBO Trips

–No. of cold start trips between 7:00 a.m. and 9:00 a.m.: 162 + 188 = 350
–No. of hot start trips between 7:00 a.m. and 9:00 a.m.: 86 + 124 = 210
–Total number of trips between 7:00 a.m. and 9:00 a.m.: 350 + 210 = 560
–Percentage of cold starts between 7:00 a.m. and 9:00 a.m.: 100(350/560) = 62.5
–Percentage of hot starts between 7:00 a.m. and 9:00 a.m.: 100(210/560) = 37.5
–Percentage of cold starts for the 24-hr period: 54.4
–Percentage of hot starts for the 24-hr period: 45.6

NHB Trips

–No. of cold start trips between 7:00 a.m. and 9:00 a.m.: 11 + 14 = 25
–No. of hot start trips between 7:00 a.m. and 9:00 a.m.: 31 + 49 = 80
–Total number of trips between 7:00 a.m. and 9:00 a.m.: 25 + 80 = 125
–Percentage of cold starts between 7:00 a.m. and 9:00 a.m.: 100(25/125) = 23.8
–Percentage of hot starts between 7:00 a.m. and 9:00 a.m.: 100(80/125) = 76.2
–Percentage of cold starts for the 24-hr period: 44.1
–Percentage of hot starts for the 24-hr period: 54.9

Tables 5 through 10 may be used when the results of an NPTS data analysis for an individual MSA indicate inadequate observations.

TABLE 8 Operating Modes at Trip Origins (Urban Area Size: 1,000,000 or More; no Subway/Rail)

Time Period	Percent HBW Trips		Percent HBO Trips		Percent NHB Trips	
	Cold Starts	Hot Starts	Cold Starts	Hot Starts	Hot Starts	
12 AM to 1 AM	96.8	3.2	68.4	31.6	42.9	57.1
	(30)	*(1)*	*(39)*	*(18)*	*(9)*	*(12)*
1 AM to 2 AM	88.5	11.5	71.8	28.2	90.0	10.0
	(23)	*(3)*	*(28)*	*(11)*	*(9)*	*(1)*
2 AM to 3 AM	90.5	9.5	63.0	37.0	71.4	28.6
	(19)	*(2)*	*(17)*	*(10)*	*(5)*	*(2)*
3 AM to 4 AM	93.3	6.7	83.3	16.7	100.0	.
	(14)	*(1)*	*(5)*	*(1)*	*(2)*	*(-)*
4 AM to 5 AM	90.5	9.5	87.5	12.5	.	.
	(38)	*(4)*	*(7)*	*(1)*	*(-)*	*(-)*
5 AM to 6 AM	94.2	5.8	80.0	20.0	100.0	.
	(130)	*(8)*	*(20)*	*(5)*	*(1)*	*(-)*
6 AM to 7 AM	94.6	5.4	67.2	32.8	23.5	76.5
	(313)	*(18)*	*(80)*	*(39)*	*(4)*	*(13)*
7 AM to 8 AM	85.9	14.1	61.0	39.0	19.5	80.5
	(519)	*(85)*	*(221)*	*(141)*	*(8)*	*(33)*
8 AM to 9 AM	79.7	20.3	59.6	40.4	13.0	87.0
	(279)	*(71)*	*(267)*	*(181)*	*(12)*	*(80)*
9 AM to 10 AM	75.6	24.4	62.4	37.6	24.4	75.6
	(118)	*(38)*	*(279)*	*(168)*	*(32)*	*(99)*
10 AM to 11 AM	75.6	24.4	60.2	39.8	24.5	75.5
	(65)	*(21)*	*(344)*	*(227)*	*(58)*	*(179)*
11 AM to 12 PM	73.5	26.5	58.4	41.6	39.9	60.1
	(61)	*(22)*	*(309)*	*(220)*	*(129)*	*(194)*
12 PM to 1 PM	66.2	33.8	55.5	44.5	40.3	59.7
	(88)	*(45)*	*(287)*	*(230)*	*(183)*	*(271)*
1 PM to 2 PM	70.8	29.2	55.9	44.1	46.2	53.8
	(80)	*(33)*	*(312)*	*(246)*	*(160)*	*(186)*
2 PM to 3 PM	71.5	28.5	51.3	48.7	42.2	57.8
	(138)	*(55)*	*(307)*	*(291)*	*(143)*	*(196)*
3 PM to 4 PM	79.6	20.4	45.7	54.3	50.3	49.7
	(215)	*(55)*	*(341)*	*(405)*	*(177)*	*(175)*
4 PM to 5 PM	79.1	20.9	44.4	55.6	53.0	47.0
	(317)	*(84)*	*(279)*	*(349)*	*(184)*	*(163)*
5 PM to 6 PM	78.6	21.4	45.2	54.8	50.3	49.7
	(382)	*(104)*	*(330)*	*(400)*	*(199)*	*(197)*
6 PM to 7 PM	69.6	30.4	51.8	48.2	44.9	55.1
	(190)	*(83)*	*(392)*	*(365)*	*(137)*	*(168)*
7 PM to 8 PM	73.8	26.2	49.1	50.9	41.7	58.3
	(107)	*(38)*	*(347)*	*(360)*	*(100)*	*(140)*
8 PM to 9 PM	78.7	21.3	50.5	49.5	45.5	54.5
	(74)	*(20)*	*(278)*	*(273)*	*(70)*	*(84)*
9 PM to 10 PM	72.4	27.6	50.5	49.5	55.9	44.1
	(63)	*(24)*	*(220)*	*(216)*	*(71)*	*(56)*
10 PM to 11 PM	78.8	21.3	60.9	39.1	62.5	37.5
	(63)	*(17)*	*(142)*	*(91)*	*(35)*	*(21)*
11 PM to 12 AM	88.5	11.5	64.5	35.5	63.0	37.0
	(54)	*(7)*	*(100)*	*(55)*	*(34)*	*(20)*
Average Daily	80.1	19.9	53.5	46.5	43.5	56.5
	(3380)	*(839)*	*(4951)*	*(4303)*	*(1762)*	*(2290)*
Notes:	*Figures in parentheses are number of observations in the cell*					

TABLE 9 Operating Modes at Trip Origins (Urban Area Size: 1,000,000 or More; with Subway/Rail)

Time Period	Percent HBW Trips		Percent HBO Trips		Percent NHB Trips	
	Cold Starts	Hot Starts	Cold Starts	Hot Starts	Cold Starts	Hot Starts
12 AM to 1 AM	93.5	6.5	75.5	24.5	82.4	17.6
	(29)	*(2)*	*(71)*	*(23)*	*(14)*	*(3)*
1 AM to 2 AM	80.0	20.0	77.3	22.7	75.0	25.0
	(12)	*(3)*	*(34)*	*(10)*	*(12)*	*(4)*
2 AM to 3 AM	100.0	.	80.8	19.2	87.5	12.5
	(11)	*(-)*	*(21)*	*(5)*	*(14)*	*(2)*
3 AM to 4 AM	78.9	21.1	73.9	26.1	83.3	16.7
	(15)	*(4)*	*(17)*	*(6)*	*(5)*	*(1)*
4 AM to 5 AM	97.4	2.6	100.0	.	100.0	.
	(38)	*(1)*	*(4)*	*(-)*	*(2)*	*. (-)*
5 AM to 6 AM	93.3	6.7	90.5	9.5	50.0	50.0
	(112)	*(8)*	*(19)*	*(2)*	*(1)*	*(1)*
6 AM to 7 AM	92.8	7.2	75.9	24.1	50.0	50.0
	(336)	*(26)*	*(63)*	*(20)*	*(2)*	*(2)*
7 AM to 8 AM	89.5	10.5	73.0	27.0	30.3	69.7
	(619)	*(73)*	*(230)*	*(85)*	*(10)*	*(23)*
8 AM to 9 AM	82.5	17.5	56.6	43.4	21.8	78.2
	(428)	*(91)*	*(304)*	*(233)*	*(19)*	*(68)*
9 AM to 10 AM	80.6	19.4	59.0	41.0	24.8	75.2
	(175)	*(42)*	*(351)*	*(244)*	*(37)*	*(112)*
10 AM to 11 AM	76.9	23.1	64.4	35.6	23.6	76.4
	(83)	*(25)*	*(407)*	*(225)*	*(56)*	*(181)*
11 AM to 12 PM	64.4	35.6	57.9	42.1	40.3	59.7
	(58)	*(32)*	*(394)*	*(287)*	*(129)*	*(191)*
12 PM to 1 PM	56.6	43.4	58.2	41.8	43.7	56.3
	(69)	*(53)*	*(452)*	*(324)*	*(226)*	*(291)*
1 PM to 2 PM	60.2	39.8	54.3	45.7	42.7	57.3
	(77)	*(51)*	*(365)*	*(307)*	*(163)*	*(219)*
2 PM to 3 PM	75.3	24.7	54.4	45.6	45.7	54.3
	(116)	*(38)*	*(403)*	*(338)*	*(179)*	*(213)*
3 PM to 4 PM	82.6	17.4	45.7	54.3	52.3	47.7
	(281)	*(59)*	*(405)*	*(481)*	*(225)*	*(205)*
4 PM to 5 PM	79.5	20.5	46.3	53.7	54.9	45.1
	(373)	*(96)*	*(358)*	*(416)*	*(226)*	*(186)*
5 PM to 6 PM	76.6	23.4	43.2	56.8	60.5	39.5
	(452)	*(138)*	*(376)*	*(494)*	*(228)*	*(149)*
6 PM to 7 PM	78.6	21.4	50.9	49.1	48.6	51.4
	(264)	*(72)*	*(442)*	*(426)*	*(139)*	*(147)*
7 PM to 8 PM	71.9	28.1	54.6	45.4	46.5	53.5
	(110)	*(43)*	*(429)*	*(357)*	*(113)*	*(130)*
8 PM to 9 PM	85.7	14.3	50.8	49.2	41.2	58.8
	(96)	*(16)*	*(330)*	*(320)*	*(73)*	*(104)*
9 PM to 10 PM	81.9	18.1	59.8	40.2	53.4	46.6
	(77)	*(17)*	*(319)*	*(214)*	*(70)*	*(61)*
10 PM to 11 PM	89.7	10.3	61.3	38.7	68.8	31.3
	(70)	*(8)*	*(195)*	*(123)*	*(44)*	*(20)*
11 PM to 12 AM	86.9	13.1	66.0	34.0	63.2	36.8
	(73)	*(11)*	*(138)*	*(71)*	*(36)*	*(21)*
Average Daily	81.4	18.6	55.0	45.0	46.6	553.6
	(3974)	*(909)*	*(6127)*	*(5011)*	*(2023)*	*(2334)*
Notes:	*Figures in parentheses are number of observations in the cell*					

When trip purposes are unknown or when a resolution by trip purpose is unnecessary, the cell frequencies may be aggregated across all trip purposes by each start mode within the analysis period. If the analysis period for a given urban area size contains no observations in a cell corresponding to a particular trip purpose, the start modes for this cell can be obtained from the nationwide averages listed in Table 2.

CONCLUSIONS

A methodology for deriving start mode fractions at trip origins is presented. This methodology may be applied to derive start modes for individual MSAs where personal travel data that can identify trip chains are available. These start modes may be used for a variety of mobile source emission modeling problems. Potential uses for these fractions include the following:

- As direct inputs to the mobile source emission models based on actual starts, such as the EMFAC model;
- As determinants of the number of vehicle trips in cold and hot starts in a trip exchange matrix used for traffic assignment and simulation studies; and
- As determinants of the VMT weighted transient and stabilized operating mode fractions used as inputs to emission rate estimation models, such as the MOBILE model.

The analysis methods used in this research to derive start mode fractions may be used for personal travel data sources other than the NPTS data source. Where available, local data are preferred to NPTS data. When such data are unavailable or individual analysis is infeasible, appropriate figures presented in several tables of this paper may be used.

The most important element lacking in the results presented in this paper is the effect of commercial trips. Intuitively, most commercial trips, such as truck trips and pickup and delivery trips, will be in the hot start mode. Therefore, the results presented may be biased toward a higher number of cold starts. It is advised that, based on sample surveys or any other available data source, appropriate adjustment factors showed be derived to account for commercial travel. The home-based trips, however, are expected to represent only personal travel and hence do not require any adjustment.

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TABLE 10 Operating Modes at Trip Origins (not in Urbanized Area)

Time Period	Percent HBW Trips		Percent HBO Trips		Percent NHB Trips	
	Cold Starts	Hot Starts	Cold Starts	Hot Starts	Cold Starts	Hot Starts
12 AM to 1 AM	83.1 (64)	16.9 (13)	67.7 (63)	32.3 (30)	75.7 (28)	24.3 (9)
1 AM to 2 AM	100.0 (29)	- (-)	60.4 (29)	39.6 (19)	83.3 (10)	16.7 (2)
2 AM to 3 AM	85.2 (23)	14.8 (4)	83.3 (20)	16.7 (4)	77.8 (7)	22.2 (2)
3 AM to 4 AM	94.7 (36)	5.3 (2)	52.6 (10)	47.4 (9)	100.0 (8)	- (-)
4 AM to 5 AM	94.1 (80)	5.9 (5)	76.9 (20)	23.1 (6)	100.0 (6)	- (-)
5 AM to 6 AM	94.3 (312)	5.7 (19)	77.3 (58)	22.7 (17)	46.2 (6)	53.8 (7)
6 AM to 7 AM	90.0 (843)	10.0 (94)	73.3 (159)	26.7 (58)	28.2 (11)	71.8 (28)
7 AM to 8 AM	85.3 (1115)	14.7 (192)	60.8 (550)	39.2 (354)	21.6 (29)	78.4 (105)
8 AM to 9 AM	78.8 (521)	21.2 (140)	59.3 (611)	40.7 (419)	23.2 (55)	76.8 (182)
9 AM to 10 AM	74.3 (197)	25.7 (68)	60.5 (743)	39.5 (485)	25.7 (83)	74.3 (240)
10 AM to 11 AM	65.0 (115)	35.0 (62)	58.3 (772)	41.7 (552)	32.9 (171)	67.1 (349)
11 AM to 12 PM	66.1 (119)	33.9 (61)	57.4 (697)	42.6 (518)	38.9 (296)	61.1 (464)
12 PM to 1 PM	54.1 (185)	45.9 (157)	49.7 (761)	50.3 (771)	44.6 (445)	55.4 (552)
1 PM to 2 PM	63.8 (196)	36.2 (111)	53.4 (683)	46.6 (597)	35.4 (279)	64.6 (509)
2 PM to 3 PM	73.7 (263)	26.3 (94)	53.9 (716)	46.1 (613)	39.7 (296)	60.3 (449)
3 PM to 4 PM	75.5 (548)	24.5 (178)	46.7 (797)	53.3 (911)	46.4 (447)	53.6 (517)
4 PM to 5 PM	73.2 (676)	26.8 (247)	45.0 (742)	55.0 (906)	48.0 (446)	52.0 (484)
5 PM to 6 PM	73.9 (785)	26.1 (277)	44.6 (817)	55.4 (1013)	44.7 (390)	55.3 (482)
6 PM to 7 PM	72.9 (382)	27.1 (142)	46.1 (857)	53.9 (1001)	35.2 (200)	64.8 (368)
7 PM to 8 PM	73.1 (204)	26.9 (75)	50.1 (778)	49.9 (776)	38.7 (188)	61.3 (298)
8 PM to 9 PM	75.1 (145)	24.9 (48)	48.0 (602)	52.0 (652)	39.1 (118)	60.9 (184)
9 PM to 10 PM	79.0 (147)	21.0 (39)	54.2 (480)	45.8 (405)	50.4 (113)	49.6 (111)
10 PM to 11 PM	84.5 (158)	15.5 (29)	57.8 (305)	42.2 (223)	65.1 (69)	34.9 (37)
11 PM to 12 AM	80.2 (105)	19.8 (26)	59.2 (155)	40.8 (107)	72.8 (59)	27.2 (22)
Average Daily	77.7 (7248)	22.3 (2083)	52.2 (11425)	47.8 (10446)	41.0 (3760)	59.0 (5401)
Notes:	*Figures in parentheses are number of observations in each cell*					

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