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# Benefits Estimates for Selected TCM Programs

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# SELECTED TCM PROGRAMS

## INTRODUCTION

This document presents applications of EPA's transportation control measure (TCM) analysis guidance, entitled *Methodologies for Estimating Emission and Travel Activity Effects of TCMs*, to six actual TCM programs. The document is intended to assist government officials, transportation planners/analysts, and other interested parties in using EPA's TCM guidance to analyze and evaluate TCM programs that have been completed, are currently in progress, or are proposed for future implementation.

The methodology outlined in EPA's guidance for estimating the effects of TCM programs consists of two phases, each of which is composed of a number of smaller steps. The first phases involves estimation of the travel activity effects of TCMs, including effects on number of trips, vehicle miles traveled (VMT), and vehicle speeds. In the second phase, the effects on trips, VMT, and speeds are used to determine effects on emissions of hydrocarbons (HC), nitrogen oxides (NOx), and carbon monoxide (CO). EPA's methodology also presents a technique for analyzing the effects of TCM packages, which involves using data on current mode choices, travel costs by mode, and travel times by mode to determine which TCMs in a package of two or more will be chosen by target populations. This type of analysis is important given that TCM programs implemented in the same area tend to interact with one another.

As noted above, this document shows how EPA's TCM methodology can be applied to six TCM programs that have actually been implemented in the U.S. These programs span a number of the TCMs listed in the 1990 Clean Air Act Amendments, including improved transit, bicycle and walking paths, and ridesharing. Using the methodology to analyze the travel activity and emission effects of these and other TCMs requires a large number of individual parameters (presented in the equations in this document) to be estimated or assumed by the user. The methodology also requires obtaining a

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substantial amount of program-specific and region-specific data. To the extent possible, the examples below make use of such data, although in some cases reasonable assumptions or default data based on national figures have been used. These cases are indicated where they occur. The implication of using assumptions or default data is that the results of the analysis will tend to be less accurate than if actual program or regional data were used. In analyzing their own TCM programs, government officials and transportation planners/analysts will likely have ready access to most of the program-specific and region-specific data required by EPA's methodology.

This document is divided into two sections. The first section presents example applications of EPA's TCM guidance to programs involving only one TCM. The second section presents example applications of the guidance to TCM packages.

# 1. ANALYSIS OF SINGLE TCMs

This section uses the methodology described in Chapters 2 and 3 of EPA's TCM guidance to estimate the travel activity effects and emissions effects of programs involving only one TCM. The TCMs addressed in these examples include telecommuting programs, walking and biking trails, transit improvements, and rideshare programs.

**Example 1:   Regional Public Transportation Authority Telecommuting Program in Maricopa County, Arizona**

<u>General Description</u>

The Regional Public Transportation Authority (RPTA) in Maricopa County, Arizona, has implemented a program to promote telecommuting in the Maricopa County area. The program has developed a telecommuting training curriculum and promotional materials to provide assistance to employers interested in developing telecommuting programs. The program began with MPO approval in September 1993. RPTA's goal for this program is to attain at least a 200 percent increase in the number of businesses and other organizations with telecommuting programs in the region.

<u>Data Sources</u>

- "Clean Air Campaign and Trip Reduction Survey," prepared by West Group Marketing Research for the Regional Public Transportation Authority, Spring 1996. (hereafter, "TRP Survey")

- "1996 Telecommuting Survey," prepared by West Group Marketing Research for RPTA/Valley Metro, June 1996. (hereafter, "Telecommuting Survey")

- *Transportation Inventory & Analysis of Existing Conditions, 1996: Maricopa County*.

- *1997 County and City Extra: Annual Metro, City, and County Data Book*, Bernan Press, 1997.

- 1990 U.S. Census data.

- *1996 Statistical Abstract of the United States*.

<u>Phase 1: Travel Activity Effects</u>

**Step 1** in the estimation of travel activity effects for the RPTA program involves an assessment of the potential trip effects from the program. For telecommuting programs, these potential effects are calculated using the following formula:

$$PT = N * F / D * 2$$

- In the formula, PT is the number of trips potentially affected, N is

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**Phase 1: Effects on Travel Activity**
Step 1:   Potential trip effects
Step 2:   Direct work and non-work trip reductions
Step 3:   Indirect work and non-work trip increases
Step 4:   Peak and off-peak trip shifts
Step 5:   Summation of distribution of trip effects among work peak, work off-peak, non-work peak, and non-work off-peak trips
Step 6:   Peak and off-peak VMT changes due to reduced number of trips
Step 7:   VMT changes due to reduced trip lengths
Step 8:   Net VMT changes
Step 9:   Peak and off-peak speed changes

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the number of
participants in the
telecommuting program,
F is the frequency of
participation (in days per
week), and D is the
average number of
commute days per week.

The appropriate value for N is derived by first calculating the total number of telecommuters in the program area, which is obtained by multiplying the total population of non-home-based employed people in the region covered by the RPTA program (1,124,600) by the percentage of respondents in the TRP Survey who telecommuted in 1996 (5 percent). The total number of telecommuters is then multiplied by the percentage of telecommuting programs in the area that are attributable to the RPTA program. Because the number of telecommuting programs in the area has increased from 57 to 260 since the beginning of the RPTA program, and because the goal of the RPTA program is to increase the number of telecommuting programs by 200 percent, it is reasonable to assume that 114 (or 57 times 200 percent) of the current 260 programs are attributable to the RPTA program. Thus, N = 1,124,600 * 0.05 * (114 / 260) = 24,655.

The value for F is derived from the Telecommuting Survey, which indicates that 27% of respondents telecommute one to three days a week, 25% telecommute four or five days a week, and 16% telecommute one to three days a month. Using average estimates for telecommute days (e.g., for participants telecommuting four or five days a week, an average of 4.5 days is used) and assuming that there are four five-day work weeks in a month, F = (0.27)(2) + (0.25)(4.5) + (0.16)(0.5) + (0.32)(0) = 1.75.

The value for D is 5, based on the fact that there are five workdays per week.

Using the data above, PT = 24,655 * 1.75 / 5 * 2 = 17,259. Thus, the potential number of trips reduced per day by the RPTA program is 17,259.

**Step 2** in the travel activity methodology involves estimating the *direct* work and non-work trip reductions from the RPTA program. Whereas the potential trip reductions calculated in Step 1 represent the total number of trips that *might* be reduced by a TCM program, direct trip reductions measure the number of trips that actually are reduced and, thus, can be less than potential trip reductions (e.g., if a telecommuter was previously using transit to commute). Direct trip reductions are calculated using the following formulas:

$$\Delta TRIPS_D = \alpha * PT$$
$$\Delta TRIPS_{D,W} = \omega * \Delta TRIPS_D$$
$$\Delta TRIPS_{D,NW} = (1 - \omega) * \Delta TRIPS_D$$

- In the formulas, $\Delta TRIPS_D$ is the total direct trip reduction, PT is (as above) the potential trip reductions, $\Delta TRIPS_{D,W}$ is the direct work trip reduction, $\Delta TRIPS_{D,NW}$ is the direct non-work trip reduction, $\alpha$ is the fraction of program participants who make a direct trip change, and $\omega$ is the fraction of trip effects that are work-related.

For telecommuting, α is defined as $-(1 - SAT) / AVO$, where SAT is the fraction of telecommuters who work in satellite offices and AVO is average vehicle occupancy. Because the information on the RPTA program does not indicate that satellite offices are used, SAT is assumed to be 0%. The value used for AVO is based on the following information from the TRP Survey: 76% of work trips are in single occupancy vehicles (SOVs) (AVO = 1), 15% of work trips are in carpools (AVO = 2.3), 5% of work trips are on buses (AVO assumed to be 15), 2% of work trips are on bicycles, and 2% of work trips are walking. Thus, $AVO = (0.76 + 0.15 + 0.05 + 0.02 + 0.02) / [(0.76 / 1) + (0.15 / 2.3) + (0.05 / 15)] = 1.21$. Using the values for SAT and AVO, $\alpha = -(1 - 0) / 1.21 = -0.83$.

**FOCUS: FROM POTENTIAL TO ACTUAL TRIP CHANGES**
The equations in Step 2 of the travel activity methodology show how the potential trip effects -- PT -- break down into actual reductions in work and non-work trips. The rectangles below show how only a fraction (α) of potential trip effects are realized, becoming $\Delta TRIPS_D$. Then, a fraction (ω) of these trip reductions are reductions in work trips, while the rest (1 - ω) are reductions in non-work trips.
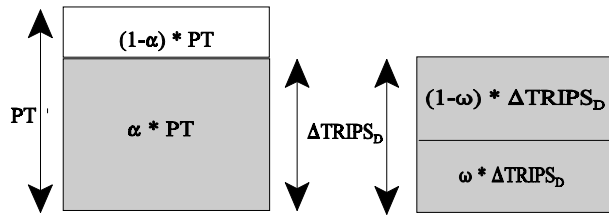


Table 2-5 in EPA's TCM guidance document indicates that, for telecommuting, the parameter ω is equal to 1. This is because telecommuting directly affects work trips only.

Using the data above, $\Delta TRIPS_D = -0.83 * 17,259 = -14,325$, $\Delta TRIPS_{D,W} = 1 * -14,325 = -14,325$, and $\Delta TRIPS_{D,NW} = (1 - 1) * -14,325 = 0$. Summarizing these results, the RPTA program is responsible for directly reducing 14,325 trips per day, all of which are work-related.

**Step 3** in the travel activity methodology involves estimating the actual *indirect* trip increases (for both work and non-work trips) from the RPTA program. Indirect trip increases are secondary effects that typically result when vehicles normally used for commuting are left at home. These increases are calculated using the following formulas:

$$\Delta TRIPS_{I,W} = INC_{W,H} * -\Delta TRIPS_D / 2$$
$$\Delta TRIPS_{I,NW} = INC_{N,H} * -\Delta TRIPS_D / 2$$

**FOCUS: WHY ACTUAL TRIP CHANGES ARE LESS THAN POTENTIAL CHANGES**
In this example, the fraction of potential trip effects that are realized (α) is defined as the fraction of telecommuters who do not work in satellite offices, divided by average vehicle occupancy. Telecommuters who use satellite offices are excluded because they still drive from home to the satellite offices. The remaining fraction is divided by average vehicle occupancy because some of the workers who become telecommuters may have been sharing rides originally. If, for example, two workers had been sharing one vehicle for commuting, and each began telecommuting (without using a satellite office), we would see a reduction of only one trip to work. Here, AVO is 2, and α would be (1-0)/2, or one-half. (Note: The parameter α is actually expressed as a negative number to reflect that TCMs are typically designed to reduce

- In the formulas, $\Delta TRIPS_{I,W}$ is the indirect work trip increase, $\Delta TRIPS_{I,NW}$ is the indirect non-work trip increase, and $INC_{W,H}$ and $INC_{N,H}$ are the rates of increased SOV work and non-work trip making by household members of TCM participants who leave their vehicles at home. The other parameter in the formulas is defined in an earlier step of the methodology.

$INC_{W,H}$ is defined as $NV * SHR * (SIZE - 1) * EMP * TG_W$, where NV is the fraction of the population that does not own a vehicle (Note: This analysis interprets this parameter to mean the percentage of drivers without a vehicle, which is estimated as the percentage of vehicle-owning households in the program area that have only one vehicle.), SHR is the fraction of shared mode trips, SIZE is average household size, EMP is the fraction of the population that is employed, and $TG_W$ is the work trip generation rate for SOV users. NV is assumed to be 42%, based on U.S. Census data for Maricopa County. The TRP Survey indicates that 15% of work trips are in carpools and 5% are on buses, resulting in an SHR estimate of 20%. (Note: It may be appropriate to use only the transit portion of shared mode trips for the SHR parameter.) SIZE is assumed to be 2.59, based on information reported in the *1997 County and City Extra*. The value for EMP is 55% and is taken from the TRP Survey, which indicates that 47% of the population in the program area is employed full-time and 8% of the population is employed part-time. The TRP Survey also reports 1,663,200 SOV work trips and 971,700 SOV commuters, and thus $TG_W$ = 1,663,200 / 971,700 = 1.71. Based on these numbers, $INC_{W,H}$ = 0.42 * 0.20 * (2.59 - 1) * 0.55 * 1.71 = 0.13.

$INC_{N,H}$ is defined as $NV * SHR * (SIZE - 1) * UNEMP * TG_N$, where NV, SHR, and SIZE are as defined above, UNEMP is the fraction of the population that is not employed, and $TG_N$ is the non-work trip generation rate for SOV users. UNEMP is simply (1 - EMP) and thus equals 45%. $TG_N$ is assumed to be the same as $TG_W$ (i.e., 1.71). Based on these numbers, $INC_{N,H}$ = 0.42 * 0.20 * (2.59 - 1) * 0.45 * 1.71 = 0.10.

> **FOCUS: TRIPS REDUCED HERE CAN INCREASE TRIPS ELSEWHERE**
> In Step 3 of the travel activity methodology, the concept behind the calculation of $INC_{W,H}$ (the increased fraction of work trips made by other household members) is that the availability of another car when one person starts participating in a TCM program (e.g., telecommuting) will prompt other workers in the household who previously had to share rides to work to begin driving. To estimate how frequently this would happen, we multiply the number of other workers in a typical household -- (SIZE - 1) * EMP -- by the fraction of work trips made by shared modes (SHR) and then by the fraction of households that might not have enough cars for every worker. The factor (SIZE - 1) is the typical number of persons in a household minus one, to allow for the worker who is now participating in the TCM program. EMP is the fraction of people who are employed, and NV is the fraction of households that have only one vehicle (and therefore might be more likely to have more workers than cars). (Note: Similar logic underlies the calculation of $INC_{N,H}$, which is the increased fraction of non-work trips made by other household members. In this fraction, the variable UNEMP is used to account for unemployed drivers in the household.)

Using the data above, $\Delta TRIPS_{I,W}$ = 0.13 * -(-14,325) / 2 = 1,862, and $\Delta TRIPS_{I,NW}$ = 0.10 * -(-14,325) / 2 = 1,433. Summarizing these results, the RPTA program is indirectly responsible for an increase of 1,862 work trips per day and 1,433 non-work trips per day.

**Step 4** in EPA's methodology for estimating travel activity effects of TCMs, which involves determining direct peak and off-peak period trip shifts, does not apply to telecommuting programs. Thus, Step 4 is not relevant to the analysis of the RPTA program.

**Step 5** in the travel activity methodology involves estimating the net trip changes from the RPTA program as distributed between work and non-work trips and peak and off-peak periods. These changes are calculated using the following formulas:

$$\Delta NETRP_{W,P} = \omega * \Delta TRIPS_{S,P} + PK_W * (\Delta TRIPS_{D,W} + \Delta TRIPS_{I,W})$$
$$\Delta NETRP_{W,OP} = \omega * \Delta TRIPS_{S,OP} + (1 - PK_W) * (\Delta TRIPS_{D,W} + \Delta TRIPS_{I,W})$$
$$\Delta NETRP_{NW,P} = (1 - \omega) * \Delta TRIPS_{S,P} + PK_{NW} * (\Delta TRIPS_{D,NW} + \Delta TRIPS_{I,NW})$$
$$\Delta NETRP_{NW,OP} = (1 - \omega) * \Delta TRIPS_{S,OP} + (1 - PK_{NW}) * (\Delta TRIPS_{D,NW} + \Delta TRIPS_{I,NW})$$

- In the formulas, $\Delta NETRP_{W,P}$ is the net work trip change in the peak period, $\Delta NETRP_{W,OP}$ is net work trip change in the off-peak period, $\Delta NETRP_{NW,P}$ is the net non-work trip change in the peak period, and $\Delta NETRP_{NW,OP}$ is the net non-work trip change in the off-peak period. $\Delta TRIPS_{S,P}$ is the change in peak period trips, and $\Delta TRIPS_{S,OP}$ is the change in off-peak period trips. $PK_W$ is the observed fraction of work trips during the peak period, and $PK_{NW}$ is the observed fraction of non-work trips during the peak period. The other parameters in the formulas are defined in earlier steps of the methodology.

Because there are no trip shifts associated with telecommuting (see Step 4), $\Delta TRIPS_{S,P}$ and $\Delta TRIPS_{S,OP}$ are each equal to 0.

The value used for $PK_W$ is 0.7, based on data for Phoenix, Arizona presented in Appendix B of the TCM guidance document, and assuming that peak travel hours are from 6 a.m. to 9 a.m. and 4 p.m. to 7 p.m. $PK_{NW}$ is assumed to be 0.3, based on an example presented in the TCM guidance document.

Using the data above, $\Delta NETRP_{W,P} = 0 + 0.7 * (-14,325 + 1,862) = -8,724$, $\Delta NETRP_{W,OP} = 0 + (1 - 0.7) * (-14,325 + 1,862) = -3,739$, $\Delta NETRP_{NW,P} = 0 + 0.3 * (0 + 1,433) = 430$, and $\Delta NETRP_{NW,OP} = 0 * (1 - 0.3) * (0 + 1,433) = 1,003$. Summarizing these results, the RPTA program results in net decreases in peak and off-peak work trips of 8,724 per day and 3,739 per day, respectively. The program also results in increases in peak and off-peak non-work trips of 430 per day and 1,003 per day, respectively.

**FOCUS: DISTRIBUTING TRIP CHANGES BY TIME-OF-DAY**
Earlier steps in the travel activity methodology have shown that trip changes resulting from TCM programs can be broken down into work trip changes and non-work trip changes. As shown in Step 5, another key distinction is between peak-period trip changes and off-peak trip changes. The parameter $PK_W$ accounts for work trips occurring during peak hours (i.e., 6:00 am to 9:00 am, and 4:00 pm to 7:00 pm). Similarly, the parameter $PK_{NW}$ accounts for non-work trips occurring during peak hours. Because most people tend to keep regular work hours, we would generally expect $PK_W$ to be greater than 0.5. In addition, because non-work trips are more discretionary than work trips, we would expect most of them to occur in off-peak periods (when

**Step 6** in the travel activity methodology involves estimating the peak and off-peak VMT changes due to the trip changes from the RPTA program. These changes are calculated using the following formulas:

$$\Delta VMT_P = (\Delta NETRP_{W,P} * DIST_W) + (\Delta NETRP_{NW,P} * DIST_{NW})$$
$$\Delta VMT_{OP} = (\Delta NETRP_{W,OP} * DIST_W) + (\Delta NETRP_{NW,OP} * DIST_{NW})$$

- In the formulas, $\Delta VMT_P$ is the change in peak-period VMT due to trip changes, $\Delta VMT_{OP}$ is the change in off-peak VMT due to trip changes, $DIST_W$ is the average VMT per trip for work trips, and $DIST_{NW}$ is the average VMT per trip

for non-work trips. The other parameters in the formulas are defined in earlier steps of the methodology.

$DIST_W$ is 13.9 miles per trip, as indicated by the TRP Survey. $DIST_{NW}$ is assumed to be 4.7 miles, based on the average passenger vehicle trip length for Maricopa County (7.1 miles, as reported in *Transportation Inventory & Analysis of Existing Conditions, 1996: Maricopa County*) and the percentages of total trips that are work and non-work related (as reported in the *1996 Statistical Abstract of the United States*).

Using the data above, $\Delta VMT_P = (-8,724 * 13.9) + (430 * 4.7) = -119,243$ and $\Delta VMT_{OP} = (-3,739 * 13.9) + (1,003 * 4.7) = -47,258$. Summarizing these results, the RPTA program reduces peak-period VMT by 119,243 miles per day due to trip changes and reduces off-peak VMT by 47,258 miles per day due to trip changes.

**Step 7** in the travel activity methodology involves estimating the VMT changes due to trip length changes resulting from the RPTA program. These changes are calculated using the following formulas:

$$\Delta VMT_{L,W} = \beta * PT * -(DIST_W - DIST_{new})$$
$$\Delta VMT_{L,NW} = \beta * PT * -(DIST_{NW} - DIST_{new})$$

- In the formulas, $\Delta VMT_{L,W}$ is the change in VMT due to work trip length changes, $\Delta VMT_{L,NW}$ is the change in VMT due to non-work trip length changes, $\beta$ is fraction of program participants who change their trip length, and $DIST_{new}$ is the new work or non-work trip length. The other parameters in the formulas are defined in earlier steps of the methodology.

For telecommuting, the guidance indicates that $\beta$ is equal to SAT. As noted in Step 2, SAT = 0 and thus $\beta = 0$.

Because no participants in the RPTA program are assumed to work at satellite work centers, $DIST_{new} = 0$ for work trips (i.e., the new work trip length is 0 because all participants work at home). Because the RPTA program does not directly affect non-work trips, $DIST_{new}$ for non-work trips is equal to $DIST_{NW}$.

Using the data above, $\Delta VMT_{L,W} = 0 * 17,259 * -(13.9 - 0) = 0$, and $\Delta VMT_{L,NW} = 0 * 17,259 * -(4.7 - 4.7) = 0$. Summarizing these results, the RPTA program does not reduce VMT through changes in trip lengths.

> **FOCUS: VMT IS REDUCED TWO WAYS**
> As shown in Step 7, in addition to reducing VMT through trip reductions, TCM programs can also reduce VMT by reducing the length of existing trips. For example, telecommuters who work at satellite work centers that are closer to home than their regular offices (so that $DIST_{new} < DIST_W$) must still drive to and from work each day. However, because these telecommuters have reduced the length of each trip, VMT decreases.

**Step 8** in the travel activity methodology involves estimating the total peak and off-peak VMT changes resulting from the RPTA program. These changes are calculated using the following formulas:

$$\Delta NETVMT_P = \Delta VMT_P + PK_W * \Delta VMT_{L,W} + PK_{NW} * \Delta VMT_{L,NW}$$
$$\Delta NETVMT_{OP} = \Delta VMT_{OP} + (1 - PK_W) * \Delta VMT_{L,W} + (1 - PK_{NW}) * \Delta VMT_{L,NW}$$

- In the formulas, $\Delta NETVMT_P$ is the total change in peak period VMT, and $\Delta NETVMT_{OP}$ is the total change in off-peak VMT. The other parameters in the formulas are defined in earlier steps of the methodology.

Using the data above, $\Delta NETVMT_P = -119{,}243 + 0.7 * 0 + 0.3 * 0 = -119{,}243$ and $\Delta NETVMT_{OP} = -47{,}258 + (1 - 0.7) * 0 + (1 - 0.3) * 0 = -47{,}258$. Summarizing these results, the RPTA program reduces peak-period VMT by a total of 119,243 miles per day and off-peak VMT by a total of 47,258 miles per day.

**Step 9** in the travel activity methodology involves estimating peak and off-peak speed changes resulting from the RPTA program. These changes are calculated using the following formulas:

$$\Delta SPD_P = (\Delta NETVMT_P / TOTVMT_P) * \epsilon_P$$
$$\Delta SPD_{OP} = (\Delta NETVMT_{OP} / TOTVMT_{OP}) * \epsilon_{OP}$$

- In the formulas, $\Delta SPD_P$ is the percentage change in peak-period speeds, $\Delta SPD_{OP}$ is the change in off-peak speeds, $TOTVMT_P$ is total peak-period VMT for the program area, $TOTVMT_{OP}$ is total off-peak VMT for the program area, $\epsilon_P$ is the elasticity of peak-period speed with respect to volume, and $\epsilon_{OP}$ is the elasticity of off-peak speed with respect to volume. The other parameters in the formulas are defined in earlier steps of the methodology.

According to *Transportation Inventory & Analysis of Existing Conditions, 1996: Maricopa County*, total VMT in Maricopa County is approximately 50 million miles per day. The TRP Survey indicates that work-related (i.e., commuter) VMT in the program area is approximately 25 million miles per day. Thus, VMT for non-work trips is approximately 25 million miles per day (i.e., 50 million total minus 25 million work-related). Combining this information with the assumptions from Step 5 that 70% of work-related trips occur in the peak period and 30% of non-work trips occur in the peak period yields a value of 25 million miles per day for each of $TOTVMT_P$ and $TOTVMT_{OP}$.

The parameter $\epsilon_P$ is assumed to be -0.75, based on an example provided in the TCM guidance document. The parameter $\epsilon_{OP}$ is assumed to be 0, because changes in off-peak VMT are not likely to affect vehicle speeds (i.e., due to a lack of congestion).

Using the data above, $\Delta SPD_P = -119{,}243 / 25{,}000{,}000 * -0.75 = 0.0036$ and $\Delta SPD_{OP} = -47{,}258 / 25{,}000{,}000 * 0 = 0$. Summarizing these results, the RPTA program increases peak-period speeds by approximately 0.36% but has no effect on off-peak speeds. (Note: Data for the Maricopa County area indicate that $\epsilon_P$ could potentially range from -0.5 to -1.94. Using these values for $\epsilon_P$ yields increases in peak-period speeds of 0.24% and 0.93%, respectively.)

> **FOCUS: HOW REDUCING VMT AFFECTS TRAVEL SPEED**
> When a TCM program reduces VMT during peak periods, we would expect to see some increase (albeit a small one) in overall fleet speeds given that fewer vehicles on the road generally translates into less congestion. In off-peak periods, however, people are typically able to travel at any speeds they choose, and thus reducing VMT during these times is not likely to have any noticeable effect on overall fleet speeds. Based on these observations, it is reasonable to assume that $\epsilon_P < 0$ and $\epsilon_{OP} = 0$.

Phase 2: Emission Effects -- STEP 1 (Trip Changes)

**Step 1** in the estimation of the emission effects for the RPTA program involves calculating the effect of trip changes on emissions. This step is broken down into seven smaller steps (1a through 1g), which are outlined below.

**Step 1a** in the emission methodology involves estimating the distribution of trip changes for the RPTA program. These changes are calculated using the following formulas:

$$\gamma_{TRIP,LDGV} = TRIP_{LDGV} / (TRIP_{LDGV} + TRIP_{LDGT1})$$
$$\gamma_{TRIP,LDGT1} = 1 - \gamma_{TRIP,LDGV}$$

- In the formulas, $\gamma_{TRIP,LDGV}$ is the fraction of *TCM-affected* trips taken by light-duty gasoline vehicles (LDGVs), $\gamma_{TRIP,LDGT1}$ is the fraction of *TCM-affected* trips taken by light-duty gasoline trucks (LDGT1s), $TRIP_{LDGV}$ is the fraction of *total* trips in the region taken by LDGVs, and $TRIP_{LDGT1}$ is the fraction of *total* trips in the region taken by LDGT1s.

(Note: Most TCMs that can be analyzed using EPA's guidance document affect only LDGVs or LDGT1s.

Thus, the sum of $\gamma_{TRIP,LDGV}$ and $\gamma_{TRIP,LDGT1}$ is typically equal to one.)

$TRIP_{LDGV}$ and $TRIP_{LDGT1}$ are derived from MOBILE5a data for Maricopa County and are equal to 0.619 and 0.173, respectively.

Using the data above, $\gamma_{TRIP,LDGV} = 0.619 / (0.619 + 0.173) = 0.782$ and $\gamma_{TRIP,LDGT1} = 1 - 0.782 = 0.218$. Summarizing these results, 78.2% of the trips affected by the RPTA program are taken by LDGVs, and 21.8% are taken by LDGT1s.

**Step 1b** in the emission methodology involves calculating cold-start and hot-start trip changes for the RPTA program. These changes are calculated using the following formulas:

$$\Delta TRIPS_{CST} = \gamma_{CST,W} * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) + \gamma_{CST,NW} * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP})$$
$$\Delta TRIPS_{HST} = (1 - \gamma_{CST,W}) * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) + (1 - \gamma_{CST,NW}) * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP})$$

- In the formulas, $\Delta TRIPS_{CST}$ is the number of cold-start trip changes, $\Delta TRIPS_{HST}$ is the number of hot-start trip changes, $\gamma_{CST,W}$ is the fraction of work trips begun in the cold-start mode, and $\gamma_{CST,NW}$ is the fraction of non-work trips begun in the

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cold-start mode. The other parameters in the formulas are defined in earlier steps of the methodology.

Because work trips are mostly cold-start trips, the guidance calls for $\gamma_{CST,W}$ to be set equal to 1. The guidance also suggests that $\gamma_{CST,NW}$ be set equal to 0.43, which is the default fraction of cold starts used in the Federal Test Procedure (FTP).

Using the data above, $\Delta TRIPS_{CST}$ = 1 * (-8,724 + -3,739) + 0.43 * (430 + 1,003) = -11,847 and $\Delta TRIPS_{HST}$ = (1 - 1) * (-8,724 + -3,739) + (1 - 0.43) * (430 + 1,003) = 817. Summarizing these results, the RPTA program results in a reduction of 11,847 cold-start trips per day and an increase of 817 hot-start trips per day.

**Step 1c** in the emission methodology involves determining cold-start and hot-start emission factors. These changes are calculated *for a given pollutant and vehicle class* using the following formulas:

> **FOCUS: EMISSION RATES BETWEEN WORK TRIPS AND NON-WORK TRIPS CAN BE DIFFERENT**
> Work trips tend to be mostly cold-start trips because vehicles typically sit for several hours at a time before morning and evening commutes (i.e., overnight, during working hours). Many non-work trips, however, are made during the day by unemployed individuals and tend to be strung together over relatively short time periods. Also, non-work trips are often made in the evening by employed individuals shortly after their evening commute trips.

$$CST = (EXH_{100\%CST,26MPH} - EXH_{100\%STB,26MPH}) * 3.59$$
$$HST = (EXH_{100\%HST,26MPH} - EXH_{100\%STB,26MPH}) * 3.59$$

- In the formulas, CST is the cold-start emission factor in grams per trip, HST is the hot-start emission factor in grams per trip, and EXH is the MOBILE emission factor in grams per mile. The 3.59 factor is the FTP driving cycle trip-start miles per trip, and 26 miles per hour is the speed for the start portion of the FTP driving cycle. (<u>Note</u>: The subscripts on EXH refer to the operating conditions and speed at which MOBILE evaluates EXH. For example, "100%CST,26MPH" indicates 100% cold-start operating mode at 26 miles per hour vehicle speed.)

Using national default data from MOBILE, $CST_{LDGV,HC}$ = (2.55 - 0.95) * 3.59 = 5.74 grams per trip, $CST_{LDGT1,HC}$ = (3.59 - 1.34) * 3.59 = 8.08 grams per trip, $HST_{LDGV,HC}$ = (1.35 - 0.95) * 3.59 = 1.44 grams per trip, and $HST_{LDGT1,HC}$ = (1.99 - 1.34) * 3.59 = 2.33 grams per trip. (Following the same methodology, the cold-start and hot-start emission factors can also be determined for NOx and CO.)

**Step 1d** in the emission methodology involves determining cold-start and hot-start emission changes for the RPTA program. These changes are calculated using the following formulas:

$$\Delta HC_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,HC}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,HC})$$
$$\Delta HC_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,HC}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,HC})$$

$$\Delta NOx_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,NOx}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,NOx})$$
$$\Delta NOx_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,NOx}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,NOx})$$

$$\Delta CO_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,CO}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,CO})$$
$$\Delta CO_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,CO}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,CO})$$

- In the formulas, $\Delta HC_{CST}$, $\Delta NOx_{CST}$, and $\Delta CO_{CST}$ are the changes in cold-start emissions for HC, NOx, and CO, respectively; and $\Delta HC_{HST}$, $\Delta NOx_{HST}$, and $\Delta CO_{HST}$ are the changes in hot-start emissions for HC, NOx, and CO, respectively. The other parameters in the formulas are defined in earlier steps of the methodology.

Using national default data from MOBILE, $\Delta HC_{CST} = (-11{,}847 * 0.782 * 5.74) + (-11{,}847 * 0.218 * 8.08) = -74{,}045$ and $\Delta HC_{HST} = (817 * 0.782 * 1.44) + (817 * 0.218 * 2.33) = 1{,}335$. Summarizing these results, the RPTA program results in a reduction in cold-start HC emissions of 74,045 grams per day and an increase in hot-start HC emissions of 1,335 grams per day. (Following the same methodology, the cold-start and hot-start emission changes can also be determined for NOx and CO.)

**Step 1e** in the emission methodology involves determining hot soak emission changes for the RPTA program. These changes are calculated using the following formula:

$$\Delta HC_{HSK} = (\Delta TRIPS_{TOTAL} * \gamma_{TRIP,LDGV} * HSK_{LDGV}) + (\Delta TRIPS_{TOTAL} * \gamma_{TRIP,LDGT1} * HSK_{LDGT1})$$

- In the formula, $\Delta HC_{HSK}$ is the change in hot soak emissions, $\Delta TRIPS_{TOTAL}$ is the total change in trips, and HSK is the hot soak emission factor in grams per trip. (Note: Hot soak emissions are HC emissions only.)

$\Delta TRIPS_{TOTAL} = \Delta NETRP_{W,P} + \Delta NETRP_{W,OP} + \Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP}$. Thus, $\Delta TRIPS_{TOTAL} = -8{,}724 + -3{,}739 + 430 + 1{,}003 = -11{,}030$.

Using national default data from MOBILE, $\Delta HC_{HSK} = (-11{,}030 * 0.782 * 3.06) + (-11{,}030 * 0.218 * 3.60) = -35{,}050$. Summarizing this result, the RPTA program results in a reduction in hot soak emissions of 35,050 grams per day.

**Step 1f** in the emission methodology involves determining diurnal emission changes for the RPTA program. These changes are calculated *for a given vehicle class* using the following formulas:

$$\Delta HC_{DNL,W} = 0.676 * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) / TPD_W * \gamma_{TRIP} * (WDI - MDI)$$
$$\Delta HC_{DNL,NW} = 0.676 * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP}) / TPD_{NW} * \gamma_{TRIP} * (WDI - MDI)$$
$$\Delta HC_{DNL} = \Delta HC_{DNL,W,LDGV} + \Delta HC_{DNL,NW,LDGV} + \Delta HC_{DNL,W,LDGT1} + \Delta HC_{DNL,NW,LDGT1}$$

- In the formulas, $\Delta HC_{DNL,W}$ is the change in diurnal emissions associated with work trips, $\Delta HC_{DNL,NW}$ is the change in diurnal emissions associated with non-work trips, and $\Delta HC_{DNL}$ is the total change in diurnal emissions. $TPD_W$ is the number of work trips per day per vehicle, and $TPD_{NW}$ is the number of non-work trips per day per vehicle. WDI is the weighted diurnal emission factor in grams, and MDI is the multi-day diurnal emission factor in grams. The other parameters in the formulas are defined in earlier steps of the methodology. (Note: Diurnal emissions are HC emissions only.)

The value used for $TPD_W$ is 2, since a commuter makes typically makes two work trips per day (i.e., one trip from home to work, one trip from work to home). $TPD_{NW}$ is equal to $TG_N$ from Step 3 of the "Travel Activity Effects" section above, and thus equals 1.71.

Using national default data from MOBILE, $\Delta HC_{DNL,W,LDGV} = 0.676 * (-8,724 + -3,739) / 2 * 0.782 * (3.30 - 6.04) = 9,026$, $\Delta HC_{DNL,NW,LDGV} = 0.676 * (430 + 1,003) / 1.71 * 0.782 * (3.30 - 6.04) = -1,214$, $\Delta HC_{DNL,W,LDGT1} = 0.676 * (-8,724 + -3,739) / 2 * 0.218 * (5.11 - 15.33) = 9,385$, $\Delta HC_{DNL,NW,LDGT1} = 0.676 * (430 + 1,003) / 1.71 * 0.218 * (5.11 - 15.33) = -1,262$, and $\Delta HC_{DNL} = 9,026 + -1,214 + 9,385 + -1,262 = 15,935$. Summarizing these results, the RPTA program results in a net increase in diurnal emissions of 15,935 grams per day.

**Step 1g** in the emission methodology involves calculating the total trip-related emission changes for the RPTA program. These changes are calculated using the following formulas:

**FOCUS: A TCM CAN INCREASE DIURNAL EMISSIONS FROM VEHICLES NOT IN USE**
Diurnal emissions (i.e., emissions resulting from daily temperature changes that occur while a vehicle is not in use) occur regardless of whether a vehicle is driven. Vehicles that are driven regularly emit more partial-day and full-day diurnal emissions than vehicles that are not driven regularly, which emit more multi-day diurnal emissions. To account for this, Step 1f of the emission methodology subtracts multi-day diurnal emissions from weighted diurnal emissions (which account for both partial-day and full-day diurnal emissions) in order to obtain a "net" effect. It is interesting to note that, although TCM programs that reduce vehicle trips generally reduce total emissions on net, diurnal emissions actually increase. This is because an increase in the number of vehicles not in use leads to an increase in multi-day diurnal emissions, which are

$$\Delta HC_{TRIP} = \Delta HC_{CST} + \Delta HC_{HST} + \Delta HC_{HSK} + \Delta HC_{DNL}$$
$$\Delta NOx_{TRIP} = \Delta NOx_{CST} + \Delta NOx_{HST}$$
$$\Delta CO_{TRIP} = \Delta CO_{CST} + \Delta CO_{HST}$$

- In the formulas, $\Delta HC_{TRIP}$, $\Delta NOx_{TRIP}$, and $\Delta CO_{TRIP}$ are the total changes in HC, NOx, and CO emissions, respectively, due to trip changes.

Using the data above, $\Delta HC_{TRIP} = -74,045 + 1,335 + -35,050 + 15,935 = -91,825$. Summarizing this result, the RPTA program results in a net decrease in trip-related HC emissions of 91,825 grams per day. (Following the same methodology, total trip-related emission changes can also be determined for NOx and CO.)

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Emission Effects -- STEP 2 (VMT Changes)

**Step 2** in the estimation of the emission effects for the RPTA program involves calculating the effect of VMT changes on emissions. This step is broken down into four smaller steps (2a through 2d), which are outlined below.

**Step 2a** in the emission methodology involves estimating the distribution of VMT changes for the RPTA program. These changes are calculated using the following formulas:

$$\gamma_{VMT,LDGV} = VMT_{LDGV} / (VMT_{LDGV} + VMT_{LDGT1})$$
$$\gamma_{VMT,LDGT1} = 1 - \gamma_{VMT,LDGV}$$

- In the formulas, $\gamma_{VMT,LDGV}$ is the fraction of *TCM-affected* VMT for light-duty gasoline vehicles (LDGVs), $\gamma_{TRIP,LDGT1}$ is the fraction of *TCM-affected* VMT for light-duty gasoline trucks (LDGT1s), $VMT_{LDGV}$ is the fraction of *total* VMT in the region for LDGVs, and $VMT_{LDGT1}$ is the fraction of *total* VMT in the region for LDGT1s. (Note: Most TCMs that can be analyzed using EPA's guidance document affect only LDGVs or LDGT1s. Thus, the sum of $\gamma_{VMT,LDGV}$ and $\gamma_{VMT,LDGT1}$ is typically equal to one.)

$VMT_{LDGV}$ and $VMT_{LDGT1}$ are taken from MOBILE5a data for Maricopa County and are equal to 0.619 and 0.173, respectively. Using the data above, $\gamma_{VMT,LDGV} = 0.619 / (0.619 + 0.173) = 0.782$ and $\gamma_{VMT,LDGT1} = 1 - 0.782 = 0.218$. Summarizing these results, 78.2% of the VMT affected by the RPTA program is by LDGVs, and 21.8% is by LDGT1s.

**Step 2b** in the emission methodology involves estimating hot-stabilized exhaust emission changes for the RPTA program. These changes are calculated using the following formulas:

$$\Delta HC_{STB,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * STB_{LDGV,HC,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * STB_{LDGT1,HC,P})$$
$$\Delta HC_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,HC,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,HC,OP})$$

$$\Delta NOx_{STB,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * STB_{LDGV,NOx,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * STB_{LDGT1,NOx,P})$$
$$\Delta NOx_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,NOx,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,NOx,OP})$$

$$\Delta CO_{STB,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * STB_{LDGV,CO,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * STB_{LDGT1,CO,P})$$
$$\Delta CO_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,CO,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,CO,OP})$$

- In the formulas, $\Delta HC_{STB,P}$, $\Delta NOx_{STB,P}$, and $\Delta CO_{STB,P}$ are the peak-period changes in hot-stabilized emissions for HC, NOx, and CO, respectively; and $\Delta HC_{STB,OP}$, $\Delta NOx_{STB,OP}$, and $\Delta CO_{STB,OP}$ are the off-peak changes in hot-stabilized emissions for HC, NOx, and CO, respectively. $STB_P$ is the hot-stabilized emission factor (in grams per mile) for each pollutant and vehicle class for the peak period (during which average vehicle speed is assumed to be 20 miles per hour), and $STB_{OP}$ is the hot-stabilized emission factor (in grams per mile) for each pollutant and vehicle class for the off-peak period (during which average vehicle speed is assumed to be 35 miles per hour). The other parameters in the formulas are defined in earlier steps of the methodology.

Using national default data from MOBILE, $\Delta HC_{STB,P} = (-119,243 * 0.782 * 1.23) + (-119,243 * 0.218 * 1.77) = -160,706$ and $\Delta HC_{STB,OP} = (-47,258 * 0.782 * 0.69) + (-47,258 * 0.218 * 0.94) = -35,184$. Summarizing these results, the RPTA program results in a reduction in peak-period hot-

stabilized HC exhaust emissions of 160,706 grams per day and a reduction in off-peak hot-stabilized HC exhaust emissions of 35,184 grams per day. (Following the same methodology, hot-stabilized exhaust emission changes can also be determined for NOx and CO.)

**Step 2c** in the emission methodology involves estimating VMT-related evaporative emission changes for the RPTA program. These changes are calculated using the following formulas:

$$\Delta HC_{VEVP,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * VEVP_{LDGV,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * VEVP_{LDGT1,P})$$
$$\Delta HC_{VEVP,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * VEVP_{LDGV,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * VEVP_{LDGT1,OP})$$

- In the formulas, $\Delta HC_{VEVP,P}$ is the change in peak-period evaporative emissions, $\Delta HC_{VEVP,OP}$ is the change in off-peak evaporative emissions, and VEVP is the VMT-related evaporative emission factor (in grams per mile) for each vehicle class and time period (peak or off-peak). The other parameters in the formulas are defined in earlier steps of the methodology. (<u>Note</u>: Evaporative emissions are HC emissions only.)

Using national default data from MOBILE, $\Delta HC_{VEVP,P} = (-119,243 * 0.782 * 0.44) + (-119,243 * 0.218 * 0.53) = -54,806$ and $\Delta HC_{VEVP,OP} = (-47,258 * 0.782 * 0.34) + (-47,258 * 0.218 * 0.44) = -17,098$. Summarizing these results, the RPTA program results in a reduction in peak-period evaporative emissions of 54,806 grams per day and a reduction in off-peak evaporative emissions of 17,098 grams per day.

> **FOCUS: SUMMING EVAPORATIVE EMISSIONS**
> In Step 2c of the emission methodology, the evaporative emission factor (VEVP) is calculated as the sum of running loss emissions, crankcase emissions, and refueling emissions. The peak-period and off-peak evaporative emission factors differ only in the running loss component, as this is the only type of evaporative emissions that is influenced by vehicle speeds.

**Step 2d** in the emission methodology involves calculating the total VMT-related emission changes for the RPTA program. These changes are calculated using the following formulas:

$$\Delta HC_{VMT} = \Delta HC_{STB,P} + \Delta HC_{STB,OP} + \Delta HC_{VEVP,P} + \Delta HC_{VEVP,OP}$$
$$\Delta NOx_{VMT} = \Delta NOx_{STB,P} + \Delta NOx_{STB,OP}$$
$$\Delta CO_{VMT} = \Delta CO_{STB,P} + \Delta CO_{STB,OP}$$

- In the formulas, $\Delta HC_{VMT}$, $\Delta NOx_{VMT}$, and $\Delta CO_{VMT}$ are the total changes in HC, NOx, and CO emissions, respectively, due to VMT changes.

Using the data above, $\Delta HC_{VMT} = -160,706 + -35,184 + -54,806 + -17,098 = -267,794$. Summarizing this result, the RPTA program results in a net decrease in VMT-related HC emissions of 267,794 grams per day. (Following the same methodology, total VMT-related emission changes can also be determined for NOx and CO.)

<u>Emission Effects -- STEP 3 (Speed Changes)</u>

**Step 3** in the estimation of the emission effects for the RPTA program involves calculating the effect of speed changes on emissions. This step is broken down into four smaller steps (3a through 3d), which are outlined below.

**Step 3a** in the emission methodology involves estimating the speeds associated with the RPTA program. These speeds are calculated using the following formulas:

$$SPEED_{P,TCM} = SPEED_{P,BASE} * (1 + \Delta SPD_P)$$
$$SPEED_{OP,TCM} = SPEED_{OP,BASE} * (1 + \Delta SPD_{OP})$$

- In the formulas, $SPEED_{P,TCM}$ is the peak-period speed after implementation of the TCM, $SPEED_{OP,TCM}$ is the off-peak speed after implementation of the TCM, $SPEED_{P,BASE}$ is the peak-period speed prior to implementation of the TCM, and $SPEED_{OP,BASE}$ is the off-peak speed prior to implementation of the TCM. The other parameters in the formulas are defined in earlier steps of the methodology.

Based on data for the national default fleet, $SPEED_{P,BASE}$ is assumed to be 20 miles per hour, and $SPEED_{OP,BASE}$ is assumed to be 35 miles per hour.

Using the data above, $SPEED_{P,TCM} = 20 * (1 + 0.0036) = 20.07$ and $SPEED_{OP,TCM} = 35 * (1 + 0) = 35$. Summarizing these results, peak-period speeds have slightly increased from 20 miles per hour to 20.07 miles per hour due to the RPTA program. Off-peak speeds have not changed due to the program. (<u>Note</u>: Using values of -0.5 and -1.94 for $\epsilon_P$ yields new peak-period speeds of 20.05 miles per hour and 20.19 miles per hour, respectively.)

**Step 3b** in the emission methodology involves estimating the total VMT for the program area after implementation of the RPTA program. These VMT figures are calculated using the following formulas:

$$VMT_{P,TCM} = TOTVMT_P + \Delta NETVMT_P$$
$$VMT_{OP,TCM} = TOTVMT_{OP} + \Delta NETVMT_{OP}$$

- In the formulas, $VMT_{P,TCM}$ is the total peak-period VMT in the program area after implementation of the TCM, and $VMT_{OP,TCM}$ is the total off-peak VMT in the program area after implementation of the TCM. The other parameters in the formulas are defined in earlier steps of the methodology.

Using data from Step 9 of the "Travel Activity Effects" section above, $VMT_{P,TCM} = 25,000,000 + -119,243 = 24,880,757$ and $VMT_{OP,TCM} = 25,000,000 + -47,258 = 24,952,742$. Summarizing these results, peak-period VMT has decreased from 25,000,000 miles per day to 24,880,757 miles per day due to the RPTA program. Off-peak VMT has decreased from 25,000,000 miles per day to 24,952,742 miles per day due to the program.

**Step 3c** in the emission methodology involves estimating peak-period and off-peak emission changes due to changes in vehicle speeds. These changes are calculated using the following formulas:

$$\Delta HC_{SPD,P} = VMT_{P,TCM} * (STB_{FLT,HC,P,TCM} + RNL_{FLT,P,TCM}) - VMT_{P,TCM} * (STB_{FLT,HC,P,BASE} + RNL_{FLT,P,BASE})$$
$$\Delta HC_{SPD,OP} = VMT_{OP,TCM} * (STB_{FLT,HC,OP,TCM} + RNL_{FLT,OP,TCM}) - VMT_{OP,TCM} * (STB_{FLT,HC,OP,BASE} + RNL_{FLT,OP,BASE})$$

$$\Delta NOx_{SPD,P} = VMT_{P,TCM} * (STB_{FLT,NOx,P,TCM} - STB_{FLT,NOx,P,BASE})$$
$$\Delta NOx_{SPD,OP} = VMT_{OP,TCM} * (STB_{FLT,NOx,OP,TCM} - STB_{FLT,NOx,OP,BASE})$$

$$\Delta CO_{SPD,P} = VMT_{P,TCM} * (STB_{FLT,CO,P,TCM} - STB_{FLT,CO,P,BASE})$$
$$\Delta CO_{SPD,OP} = VMT_{OP,TCM} * (STB_{FLT,CO,OP,TCM} - STB_{FLT,CO,OP,BASE})$$

- In the formulas, $\Delta HC_{SPD,P}$, $\Delta NOx_{SPD,P}$, and $\Delta CO_{SPD,P}$ are the peak-period changes in emissions for HC, NOx, and CO, respectively, due to a change in speeds; and $\Delta HC_{SPD,OP}$, $\Delta NOx_{SPD,OP}$, and $\Delta CO_{SPD,OP}$ are the off-peak changes in emissions for HC, NOx, and CO, respectively, due to a change in speeds. $STB_{FLT}$ is the fleet-wide hot-stabilized emission factor (in grams per mile) for each pollutant, time period (i.e., peak or off-peak), and scenario (i.e., base or TCM). $RNL_{FLT}$ is the fleet-wide running loss emission factor (in grams per mile) for each time period and scenario. The other parameters in the formulas are defined in earlier steps of the methodology.

Based on data showing the relationship between vehicle speed and emissions, this analysis assumes that the elasticity of $STB_{FLT}$ with respect to speed is -1 for HC, 0 for NOx, and -1 for CO. Thus, a 1% increase in speed is assumed to result in a 1% decrease in HC and CO emissions (on a grams per mile basis) and no change in NOx emissions. The elasticity of $RNL_{FLT}$ with respect to speed is also assumed to be -1.

Using national default data from MOBILE, $\Delta HC_{SPD,P} = 24,880,757 * (1.670 + 0.211) - 24,880,757 * (1.676 + 0.212) = -174,165$ and $\Delta HC_{SPD,OP} = 24,952,742 * (1.938 + 0.120) - 24,952,742 * (1.938 + 0.120) = 0$. Summarizing these results, the RPTA program results in a decrease in speed-related HC emissions of 174,165 grams per day for the peak

> **FOCUS: FLEET-WIDE EMISSIONS FACTORS IN THIS STEP**
> It is important to note that the emission factors used in Step 3c of the emission methodology are <u>fleet-wide</u>. The emission factors used throughout the remainder of the methodology are specific to individual vehicle classes (e.g., LDGV, LDGT).

period but does not change speed-related HC emissions for the off-peak period. (Following the same methodology, the peak-period and off-peak emission changes due to changes in speeds can also be determined for NOx and CO.) (<u>Note</u>: Using values of -0.5 and -1.94 for $\epsilon_P$ yields decreases in speed-related HC emissions of 124,404 grams per day and 447,854 grams per day, respectively.)

**Step 3d** in the emission methodology involves calculating the total speed-related emission changes for the RPTA program. These changes are calculated using the following formulas:

$$\Delta HC_{SPD} = \Delta HC_{SPD,P} + \Delta HC_{SPD,OP}$$
$$\Delta NOx_{SPD} = \Delta NOx_{SPD,P} + \Delta NOx_{SPD,OP}$$
$$\Delta CO_{SPD} = \Delta CO_{SPD,P} + \Delta CO_{SPD,OP}$$

- In the formulas, $\Delta HC_{SPD}$, $\Delta NOx_{SPD}$, and $\Delta CO_{SPD}$ are the total changes in HC, NOx, and CO emissions, respectively, due to speed changes.

Using the data above, $\Delta HC_{SPD} = -174,165 + 0 = -174,165$. Summarizing this result, the RPTA program results in a net decrease in speed-related HC emissions of 174,165 grams per day. (Following the same methodology, total speed-related emission changes can also be determined for NOx and CO.) (<u>Note</u>: Using values of -0.5 and -1.94 for $\epsilon_P$ yields net decreases in speed-related HC emissions of 124,404 grams per day and 447,854 grams per day, respectively.)

**Step 4** in the estimation of the emission effects for the RPTA program involves calculating the total changes in HC, NOx, and CO emissions. These changes are calculated using the following formulas:

$$\Delta HC = \Delta HC_{TRIP} + \Delta HC_{VMT} + \Delta HC_{SPD}$$
$$\Delta NOx = \Delta NOx_{TRIP} + \Delta NOx_{VMT} + \Delta NOx_{SPD}$$
$$\Delta CO = \Delta CO_{TRIP} + \Delta CO_{VMT} + \Delta CO_{SPD}$$

- In the formulas, $\Delta HC$, $\Delta NOx$, and $\Delta CO$ are the total changes in HC, NOx, and CO emissions, respectively, due to the TCM program.

Using the data above, $\Delta HC$ = -91,825 + -267,794 + -174,165 = -533,784. Summarizing this result, the RPTA program results in a net decrease in HC emissions of 533,784 grams per day, or approximately 0.59 tons per day. (Following the same methodology, total emission changes can also be determined for NOx and CO.) (<u>Note</u>: Using values of -0.5 and -1.94 for $\epsilon_P$ yields net decreases in HC emissions of 0.53 tons per day and 0.89 tons per day, respectively.)

**Example 2:    Atlanta/DeKalb Greenway Trails**

General Description

        In 1994, the PATH Foundation funded the construction of 20 miles of trails built adjacent to highways servicing downtown Atlanta.  The main objective of the project was to reduce traffic congestion by encouraging commuters to bike or walk to work rather than drive.  The project also attempted to capture trips to schools and shops.  The following analysis extrapolates data available for the 2.5-mile Westside Trail to estimate total reductions in trips, VMT, and emissions for the 20-mile trail network.  Ultimately, the PATH Foundation expects to construct over 110 miles of trails by the year 2000.  Thus, the impact the trails have on travel activity and emissions will probably be much greater in the future than this analysis indicates.

Data Sources

-       Conversations with Edwin McBrayer, Executive Director, PATH Foundation, March 9 and 13, 1997.

-       1990 U.S. Census data.

-       *1996 Statistical Abstract of the United States*.

-       Texas Transportation Institute web page.

Phase 1: Travel Activity Effects

        **Step 1** in the estimation of travel activity effects for the PATH project involves an assessment of the potential trip effects from the project.  For this TCM, these potential effects are calculated using the following *user-defined* formula:

$$PT = N$$

-       In the formula, PT is the potential effect on trips, and N is the total number of vehicles traveling on roadways adjacent to trails.

**Phase 1: Effects on Travel Activity**
Step 1:  Potential trip effects
Step 2:  Direct work and non-work trip reductions
Step 3:  Indirect work and non-work trip increases
Step 4:  Peak and off-peak trip shifts
Step 5:  Summation of distribution of trip effects among work peak, work off-peak, non-work peak, and non-work off-peak trips
Step 6:  Peak and off-peak VMT changes due to reduced number of trips
Step 7:  VMT changes due to reduced trip lengths
Step 8:  Net VMT changes
Step 9:  Peak and off-peak speed changes

        The appropriate value for N is derived using information from the Atlanta Regional Commission (ARC) indicating that approximately 18,000 vehicles use roadways adjacent to the 2.5-mile Westside Trail on a given day.  Assuming that the remaining trails comprising the 20-mile network are built along roads that experience similar usage, the number of vehicles using roadways adjacent to trails is 144,000.  Thus, the potential number of trips reduced per day by the PATH project is 144,000.

        **Step 2** in the travel activity methodology involves estimating the *direct* work and non-work trip reductions from the PATH project.  Whereas the potential trip reductions calculated in Step 1 represent the total number of trips that *might* be reduced by a TCM program, direct trip reductions measure the

number of trips that actually are reduced and, thus, can be less than potential trip reductions (i.e., not all vehicle passengers will switch to biking or walking ). Direct trip reductions are calculated using the following formulas:

$$\Delta TRIPS_D = \alpha * PT$$
$$\Delta TRIPS_{D,W} = \omega * \Delta TRIPS_D$$
$$\Delta TRIPS_{D,NW} = (1 - \omega) * \Delta TRIPS_D$$

- In the formulas, $\Delta TRIPS_D$ is the change in total direct trips, PT is (as above) the potential trip reductions, $\Delta TRIPS_{D,W}$ is the change in direct work trips, $\Delta TRIPS_{D,NW}$ is the change in direct non-work trips, $\alpha$ is the fraction of program participants who make a direct trip change, and $\omega$ is the fraction of trip effects that are work-related.

The parameter $\alpha$ is assumed to be -0.04, based on information provided by ARC officials.

For TCM projects that influence work and non-work travel equally (such as the PATH project), the TCM guidance calls for the parameter $\omega$ to be set equal to the fraction of travel that is work-related. Thus, $\omega$ is assumed to be 0.3, based on information provided in the *1996 Statistical Abstract of the United States*.

Using the data above, $\Delta TRIPS_D$ = -0.04 * 144,000 = -5,760, $\Delta TRIPS_{D,W}$ = 0.3 * -5,760 = -1,728, and $\Delta TRIPS_{D,NW}$ = (1 - 0.3) * -5,760 = -4,032. Summarizing these results, the PATH project is responsible for directly reducing 1,728 work trips per day and 4,032 non-work trips per day.

**Step 3** in the travel activity methodology involves estimating the actual *indirect* trip increases (for both work and non-work trips) from the PATH project. Indirect trip increases are secondary effects that typically result when vehicles normally used for commuting or other trips are left at home. These increases are calculated using the following formulas:

$$\Delta TRIPS_{I,W} = INC_{W,H} * -\Delta TRIPS_D / 2$$
$$\Delta TRIPS_{I,NW} = INC_{N,H} * -\Delta TRIPS_D / 2$$

- In the formulas, $\Delta TRIPS_{I,W}$ is the indirect work trip increase, $\Delta TRIPS_{I,NW}$ is the indirect non-work trip increase, and $INC_{W,H}$ and $INC_{N,H}$ are the rates of increased SOV work and non-work trip making by household members of TCM participants who leave their vehicles at home. The other parameter in the formulas is defined in an earlier step of the methodology.

$INC_{W,H}$ is defined as NV * SHR * (SIZE - 1) * EMP * $TG_W$, where NV is the fraction of the population that does not own a vehicle (<u>Note</u>: This analysis interprets this parameter to mean the percentage of drivers without a vehicle, which is estimated as the percentage of vehicle-owning households in the program area that have only one vehicle.), SHR is the fraction of shared mode trips, SIZE is average household size, EMP is the fraction of the population that is employed, and $TG_W$ is the work trip generation rate for SOV users. Based on 1990 U.S. Census data for DeKalb County, NV is assumed to be 38%, SHR is assumed to be 19%, SIZE is assumed to be 2.56, and EMP is assumed to be 70%. $TG_W$ is assumed to equal 2. Based on these numbers, $INC_{W,H}$ = 0.38 * 0.19 * (2.56 - 1) * 0.7 * 2 = 0.16.

$INC_{N,H}$ = NV * SHR * (SIZE - 1) * UNEMP * $TG_N$, where NV, SHR, and SIZE are as defined above, UNEMP is the fraction of the population that is not employed, and $TG_N$ is the non-work trip generation rate for SOV users. UNEMP is simply (1 - EMP) and thus equals 30%. $TG_N$ is assumed to be the same as $TG_W$ (i.e., 2). Based on these numbers, $INC_{N,H}$ = 0.38 * 0.19 * (2.56 - 1) * 0.3 * 2 = 0.07.

Using the data above, $\Delta TRIPS_{I,W} = 0.16 * \text{-}(\text{-}5{,}760) / 2 = 461$, and $\Delta TRIPS_{I,NW} = 0.07 * \text{-}(\text{-}5{,}760)$ / 2 = 202. Summarizing these results, the PATH project is indirectly responsible for an increase of 461 work trips per day and 202 non-work trips per day. Summarizing these results, the PATH project is indirectly responsible for an increase of 461 work trips per day and 202 non work trips per day.

**Step 4** in EPA's methodology for estimating travel activity effects of TCMs, which involves determining direct peak and off-peak period trip shifts, does not apply to walking and biking trails. Thus, Step 4 is not relevant to the analysis of the PATH project.

**Step 5** in the travel activity methodology involves estimating the net trip changes from the PATH project as distributed between work and non-work trips and peak and off-peak periods. These changes are calculated using the following formulas:

$$\Delta NETRP_{W,P} = \omega * \Delta TRIPS_{S,P} + PK_W * (\Delta TRIPS_{D,W} + \Delta TRIPS_{I,W})$$
$$\Delta NETRP_{W,OP} = \omega * \Delta TRIPS_{S,OP} + (1 - PK_W) * (\Delta TRIPS_{D,W} + \Delta TRIPS_{I,W})$$
$$\Delta NETRP_{NW,P} = (1 - \omega) * \Delta TRIPS_{S,P} + PK_{NW} * (\Delta TRIPS_{D,NW} + \Delta TRIPS_{I,NW})$$
$$\Delta NETRP_{NW,OP} = (1 - \omega) * \Delta TRIPS_{S,OP} + (1 - PK_{NW}) * (\Delta TRIPS_{D,NW} + \Delta TRIPS_{I,NW})$$

- In the formulas, $\Delta NETRP_{W,P}$ is the net work trip change in the peak period, $\Delta NETRP_{W,OP}$ is net work trip change in the off-peak period, $\Delta NETRP_{NW,P}$ is the net non-work trip change in the peak period, and $\Delta NETRP_{NW,OP}$ is the net non-work trip change in the off-peak period. $\Delta TRIPS_{S,P}$ is the change in peak period trips, and $\Delta TRIPS_{S,OP}$ is the change in off-peak period trips. $PK_W$ is the observed fraction of work trips during the peak period, and $PK_{NW}$ is the observed fraction of non-work trips during the peak period. The other parameters in the formulas are defined in earlier steps of the methodology.

Because there are no trip shifts associated with walking and biking trails (see Step 4), $\Delta TRIPS_{S,P}$ and $\Delta TRIPS_{S,OP}$ are each equal to 0.

The values used for $PK_W$ and $PK_{NW}$ are 0.6 and 0.3, respectively, based on an example shown in the TCM guidance document.

Using the data above, $\Delta NETRP_{W,P} = 0 + 0.6 * (\text{-}1{,}728 + 461) = \text{-}760$, $\Delta NETRP_{W,OP} = 0 + (1 - 0.6) * (\text{-}1{,}728 + 461) = \text{-}507$, $\Delta NETRP_{NW,P} = 0 + 0.3 * (\text{-}4{,}032 + 202) = \text{-}1{,}149$, and $\Delta NETRP_{NW,OP} = 0 + (1 - 0.3) * (\text{-}4{,}032 + 202) = \text{-}2{,}681$. Summarizing these results, the PATH project results in net decreases in peak and off-peak work trips of 760 per day and 507 per day, respectively. The project also results in decreases in peak and off-peak non-work trips of 1,149 per day and 2,681 per day, respectively.

**Step 6** in the travel activity methodology involves estimating the peak and off-peak VMT changes due to the trip changes from the PATH project. These changes are calculated using the following formulas:

$$\Delta VMT_P = (\Delta NETRP_{W,P} * DIST_W) + (\Delta NETRP_{NW,P} * DIST_{NW})$$
$$\Delta VMT_{OP} = (\Delta NETRP_{W,OP} * DIST_W) + (\Delta NETRP_{NW,OP} * DIST_{NW})$$

- In the formulas, $\Delta VMT_P$ is the change in peak-period VMT due to trip changes, $\Delta VMT_{OP}$ is the change in off-peak VMT due to trip changes, $DIST_W$ is the average VMT per trip for work trips, and $DIST_{NW}$ is the average VMT per trip for non-work trips. The other parameters in the formulas are defined in earlier steps of the methodology.

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DIST$_W$ is 13 miles per trip, as estimated by ARC. DIST$_{NW}$ is assumed to be 8.1 miles, based on data from the *1996 Statistical Abstract of the United States*.

Using the data above, $\Delta VMT_P$ = (-760 * 13) + (-1,149 * 8.1) = -19,187 and $\Delta VMT_{OP}$ = (-507 * 13) + (-2,681 * 8.1) = -28,307. Summarizing these results, the PATH project reduces peak-period VMT by 19,187 miles per day due to trip changes and reduces off-peak VMT by 28,307 miles per day due to trip changes.

**Step 7** in the travel activity methodology involves estimating the VMT changes due to trip length changes resulting from the PATH project. These changes are calculated using the following formulas:

$$\Delta VMT_{L,W} = \beta * PT * -(DIST_W - DIST_{new})$$
$$\Delta VMT_{L,NW} = \beta * PT * -(DIST_{NW} - DIST_{new})$$

- In the formulas, $\Delta VMT_{L,W}$ is the change in VMT due to work trip length changes, $\Delta VMT_{L,NW}$ is the change in VMT due to non-work trip length changes, $\beta$ is fraction of program participants who change their trip length, and DIST$_{new}$ is the new work or non-work trip length. The other parameters in the formulas are defined in earlier steps of the methodology.

Although it is conceivable that trail users may drive to a trail and walk or bicycle the rest of the way, this analysis assumes that no trail users do so. Thus, both $\beta$ and DIST$_{new}$ are set equal to 0.

Using the data above, $\Delta VMT_{L,W}$ = 0 * 144,000 * -(13 - 0) = 0, and $\Delta VMT_{L,NW}$ = 0 * 144,000 * -(8.1 - 0) = 0. Summarizing these results, the PATH project does not reduce VMT through changes in trip lengths.

**Step 8** in the travel activity methodology involves estimating the total peak and off-peak VMT changes resulting from the PATH project. These changes are calculated using the following formulas:

$$\Delta NETVMT_P = \Delta VMT_P + PK_W * \Delta VMT_{L,W} + PK_{NW} * \Delta VMT_{L,NW}$$
$$\Delta NETVMT_{OP} = \Delta VMT_{OP} + (1 - PK_W) * \Delta VMT_{L,W} + (1 - PK_{NW}) * \Delta VMT_{L,NW}$$

- In the formulas, $\Delta NETVMT_P$ is the total change in peak period VMT, and $\Delta NETVMT_{OP}$ is the total change in off-peak VMT. The other parameters in the formulas are defined in earlier steps of the methodology.

Using the data above, $\Delta NETVMT_P = -19{,}187 + 0.6 * 0 + 0.3 * 0 = -19{,}187$ and $\Delta NETVMT_{OP}$ $= -28{,}307 + (1 - 0.6) * 0 + (1 - 0.3) * 0 = -28{,}307$. Summarizing these results, the PATH project reduces peak-period VMT by a total of 19,187 miles per day and off-peak VMT by a total of 28,307 miles per day.

**Step 9** in the travel activity methodology involves estimating peak and off-peak speed changes resulting from the PATH project. These changes are calculated using the following formulas:

$$\Delta SPD_P = (\Delta NETVMT_P / TOTVMT_P) * \epsilon_P$$
$$\Delta SPD_{OP} = (\Delta NETVMT_{OP} / TOTVMT_{OP}) * \epsilon_{OP}$$

- In the formulas, $\Delta SPD_P$ is the percentage change in peak-period speeds, $\Delta SPD_{OP}$ is the change in off-peak speeds, $TOTVMT_P$ is total peak-period VMT for the program area, $TOTVMT_{OP}$ is total off-peak VMT for the program area, $\epsilon_P$ is the elasticity of peak-period speed with respect to volume, and $\epsilon_{OP}$ is the elasticity of off-peak speed with respect to volume. The other parameters in the formulas are defined in earlier steps of the methodology.

According to data from the Texas Transportation Institute, total VMT in metropolitan Atlanta is approximately 80 million miles per day. Based on information from a local transportation agency indicating that 40 percent of travel occurs during peak periods and 60 percent occurs during off-peak periods, $TOTVMT_P$ is approximately 32 million miles per day and $TOTVMT_{OP}$ is approximately 48 million miles per day.

The parameter $\epsilon_P$ is assumed to be -0.75, based on an example provided in the TCM guidance document. The parameter $\epsilon_{OP}$ is assumed to be 0, because changes in off-peak VMT are not likely to affect vehicle speeds (i.e., due to a lack of congestion).

Using the data above, $\Delta SPD_P = -19{,}187 / 32{,}000{,}000 * -0.75 = 0.0004$ and $\Delta SPD_{OP} = -28{,}307 / 48{,}000{,}000 * 0 = 0$. Summarizing these results, the PATH project increases peak-period speeds by approximately 0.04% but has no effect on off-peak speeds.

**Step 1** in the estimation of the emission effects for the PATH project involves calculating the effect of trip changes on emissions. This step is broken down into seven smaller steps (1a through 1g), which are outlined below.

**Step 1a** in the emission methodology involves estimating the distribution of trip changes for the PATH project. These changes are calculated using the following formulas:

$$\gamma_{TRIP,LDGV} = TRIP_{LDGV} / (TRIP_{LDGV} + TRIP_{LDGT1})$$
$$\gamma_{TRIP,LDGT1} = 1 - \gamma_{TRIP,LDGV}$$

- In the formulas, $\gamma_{TRIP,LDGV}$ is the fraction of *TCM-affected* trips taken by light-duty gasoline vehicles (LDGVs), $\gamma_{TRIP,LDGT1}$ is the fraction of *TCM-affected* trips taken by light-duty gasoline trucks (LDGT1s), $TRIP_{LDGV}$ is the fraction of *total* trips in the region taken by LDGVs, and $TRIP_{LDGT1}$ is the fraction of *total* trips in the region taken by LDGT1s. (Note: Most TCMs that can be analyzed using EPA's guidance document affect only LDGVs or LDGT1s. Thus, the sum of $\gamma_{TRIP,LDGV}$ and $\gamma_{TRIP,LDGT1}$ is typically equal to one.)

**Phase 2: Effects on Emissions**
Step 1: Effect of trip changes on emissions
   1a: Distribution of trip changes among vehicle types
   1b: Changes in cold-start and hot-start trips
   1c: Cold-start and hot-start emission factors by pollutant and vehicle type
   1d: Cold-start and hot-start emission changes for the project
   1e: Hot-soak emission changes
   1f: Diurnal changes by vehicle type
   1g: Summation of trip related emission changes
Step 2: Effect of VMT changes on emissions
   2a: Distribution of VMT changes among vehicle types
   2b: Hot-stabilized exhaust emission changes by vehicle type
   2c: VMT-related evaporative emission changes
   2d: Summation of VMT-related emission changes
Step 3: Emission effects due to speed changes
   3a: Peak and off-peak speed after implementation
   3b: Peak and off-peak VMT after implementation
   3c: Peak and off-peak emissions changes due to changes in speeds
   3d: Summation of speed related changes

$TRIP_{LDGV}$ and $TRIP_{LDGT1}$ are assumed to equal 0.626 and 0.171, respectively. These values are based on the national average default values used in MOBILE.

Using the data above, $\gamma_{TRIP,LDGV} = 0.626 / (0.626 + 0.171) = 0.785$ and $\gamma_{TRIP,LDGT1} = 1 - 0.785 = 0.215$. Summarizing these results, 78.5% of the trips affected by the PATH project are taken by LDGVs, and 21.5% are taken by LDGT1s.

**Step 1b** in the emission methodology involves calculating cold-start and hot-start trip changes for the PATH project. These changes are calculated using the following formulas:

$$\Delta TRIPS_{CST} = \gamma_{CST,W} * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) + \gamma_{CST, NW} * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP})$$
$$\Delta TRIPS_{HST} = (1 - \gamma_{CST,W}) * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) + (1 - \gamma_{CST,NW}) * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP})$$

- In the formulas, $\Delta TRIPS_{CST}$ is the number of cold-start trip changes, $\Delta TRIPS_{HST}$ is the number of hot-start trip changes, $\gamma_{CST,W}$ is the fraction of work trips begun in the cold-start mode, and $\gamma_{CST, NW}$ is the fraction of non-work trips begun in the

cold-start mode.  The other parameters in the formulas are defined in earlier
steps of the methodology.

Because work trips are mostly cold-start trips, the guidance calls for $\gamma_{CST,W}$ to be set equal to 1. The guidance also suggests that $\gamma_{CST,NW}$ be set equal to 0.43, which is the default fraction of cold starts used in the Federal Test Procedure (FTP).

Using the data above, $\Delta TRIPS_{CST} = 1 * (-760 + -507) + 0.43 * (-1,149 + -2,681) = -2,914$ and $\Delta TRIPS_{HST} = (1 - 1) * (-760 + -507) + (1 - 0.43) * (-1,149 + -2,681) = -2,183$.  Summarizing these results, the PATH project results in a reduction of 2,914 cold-start trips per day and a reduction of 2183 hot-start trips per day.

**Step 1c** in the emission methodology involves determining cold-start and hot-start emission factors.  These changes are calculated *for a given pollutant and vehicle class* using the following formulas:

$$CST = (EXH_{100\%CST,26MPH} - EXH_{100\%STB,26MPH}) * 3.59$$
$$HST = (EXH_{100\%HST,26MPH} - EXH_{100\%STB,26MPH}) * 3.59$$

- In the formulas, CST is the cold-start emission factor in grams per trip, HST is the hot-start emission factor in grams per trip, and EXH is the MOBILE emission factor in grams per mile.  The 3.59 factor is the FTP driving cycle trip-start miles per trip, and 26 miles per hour is the speed for the start portion of the FTP driving cycle.  (Note: The subscripts on EXH refer to the operating conditions and speed at which MOBILE evaluates EXH.  For example, "100%CST,26MPH" indicates 100% cold-start operating mode at 26 miles per hour vehicle speed.)

Using national default data from MOBILE, $CST_{LDGV,HC} = (2.55 - 0.95) * 3.59 = 5.74$ grams per trip, $CST_{LDGT1,HC} = (3.59 - 1.34) * 3.59 = 8.08$ grams per trip, $HST_{LDGV,HC} = (1.35 - 0.95) * 3.59 = 1.44$ grams per trip, and $HST_{LDGT1,HC} = (1.99 - 1.34) * 3.59 = 2.33$ grams per trip.  (Following the same methodology, the cold-start and hot-start emission factors can also be determined for NOx and CO.)

**Step 1d** in the emission methodology involves determining cold-start and hot-start emission changes for the PATH project.  These changes are calculated using the following formulas:

$$\Delta HC_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,HC}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,HC})$$
$$\Delta HC_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,HC}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,HC})$$

$$\Delta NOx_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,NOx}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,NOx})$$
$$\Delta NOx_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,NOx}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,NOx})$$

$$\Delta CO_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,CO}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,CO})$$
$$\Delta CO_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,CO}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,CO})$$

- In the formulas, $\Delta HC_{CST}$, $\Delta NOx_{CST}$, and $\Delta CO_{CST}$ are the changes in cold-start emissions for HC, NOx, and CO, respectively; and $\Delta HC_{HST}$, $\Delta NOx_{HST}$, and $\Delta CO_{HST}$ are the changes in hot-start emissions for HC, NOx, and CO, respectively.  The other parameters in the formulas are defined in earlier steps of the methodology.

Using national default data from MOBILE, $\Delta HC_{CST} = (-2{,}914 * 0.785 * 5.74) + (-2{,}914 * 0.215 * 8.08) = -18{,}192$ and $\Delta HC_{HST} = (-2{,}183 * 0.785 * 1.44) + (-2{,}183 * 0.215 * 2.33) = -3{,}561$. Summarizing these results, the PATH project results in a reduction in cold-start HC emissions of 18,192 grams per day and a reduction in hot-start HC emissions of 3,561 grams per day. (Following the same methodology, the cold-start and hot-start emission changes can also be determined for NOx and CO.)

**Step 1e** in the emission methodology involves determining hot soak emission changes for the PATH project. These changes are calculated using the following formula:

$$\Delta HC_{HSK} = (\Delta TRIPS_{TOTAL} * \gamma_{TRIP,LDGV} * HSK_{LDGV}) + (\Delta TRIPS_{TOTAL} * \gamma_{TRIP,LDGT1} * HSK_{LDGT1})$$

- In the formula, $\Delta HC_{HSK}$ is the change in hot soak emissions, $\Delta TRIPS_{TOTAL}$ is the total change in trips, and HSK is the hot soak emission factor in grams per trip. (<u>Note</u>: Hot soak emissions are HC emissions only.)

$\Delta TRIPS_{TOTAL} = \Delta NETRP_{W,P} + \Delta NETRP_{W,OP} + \Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP}$. Thus, $\Delta TRIPS_{TOTAL} = -760 + -507 + -1{,}149 + -2{,}681 = -5{,}097$.

Using national default data from MOBILE, $\Delta HC_{HSK} = (-5{,}097 * 0.785 * 3.06) + (-5{,}097 * 0.215 * 3.60) = -16{,}189$. Summarizing this result, the PATH project results in a reduction in hot soak emissions of 16,189 grams per day.

**Step 1f** in the emission methodology involves determining diurnal emission changes for the PATH project. These changes are calculated *for a given vehicle class* using the following formulas:

$$\Delta HC_{DNL,W} = 0.676 * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) / TPD_W * \gamma_{TRIP} * (WDI - MDI)$$
$$\Delta HC_{DNL,NW} = 0.676 * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP}) / TPD_{NW} * \gamma_{TRIP} * (WDI - MDI)$$
$$\Delta HC_{DNL} = \Delta HC_{DNL,W,LDGV} + \Delta HC_{DNL,NW,LDGV} + \Delta HC_{DNL,W,LDGT1} + \Delta HC_{DNL,NW,LDGT1}$$

- In the formulas, $\Delta HC_{DNL,W}$ is the change in diurnal emissions associated with work trips, $\Delta HC_{DNL,NW}$ is the change in diurnal emissions associated with non-work trips, and $\Delta HC_{DNL}$ is the total change in diurnal emissions. $TPD_W$ is the number of work trips per day per vehicle, and $TPD_{NW}$ is the number of non-work trips per day per vehicle. WDI is the weighted diurnal emission factor in grams, and MDI is the multi-day diurnal emission factor in grams. The other parameters in the formulas are defined in earlier steps of the methodology. (<u>Note</u>: Diurnal emissions are HC emissions only.)

The value used for $TPD_W$ is 2, since a commuter makes typically makes two work trips per day (i.e., one trip from home to work, one trip from work to home). $TPD_{NW}$ is equal to $TG_N$ from Step 3 of the "Travel Activity Effects" section above, and thus equals 2.

Using national default data from MOBILE, $\Delta HC_{DNL,W,LDGV} = 0.676 * (-760 + -507) / 2 * 0.785 * (3.30 - 6.04) = 921$, $\Delta HC_{DNL,NW,LDGV} = 0.676 * (-1{,}149 + -2{,}681) / 2 * 0.785 * (3.30 - 6.04) = 2{,}784$, $\Delta HC_{DNL,W,LDGT1} = 0.676 * (-760 + -507) / 2 * 0.215 * (5.11 - 15.33) = 941$, $\Delta HC_{DNL,NW,LDGT1} = 0.676 * (-1{,}149 + -2{,}681) / 2 * 0.215 * (5.11 - 15.33) = 2{,}844$, and $\Delta HC_{DNL} = 921 + 2{,}784 + 941 + 2{,}844 = 7{,}490$. Summarizing these results, the PATH project results in an increase in diurnal emissions of 7,490 grams per day.

**Step 1g** in the emission methodology involves calculating the total trip-related emission changes for the PATH project. These changes are calculated using the following formulas:

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$$\Delta HC_{TRIP} = \Delta HC_{CST} + \Delta HC_{HST} + \Delta HC_{HSK} + \Delta HC_{DNL}$$
$$\Delta NOx_{TRIP} = \Delta NOx_{CST} + \Delta NOx_{HST}$$
$$\Delta CO_{TRIP} = \Delta CO_{CST} + \Delta CO_{HST}$$

- In the formulas, $\Delta HC_{TRIP}$, $\Delta NOx_{TRIP}$, and $\Delta CO_{TRIP}$ are the total changes in HC, NOx, and CO emissions, respectively, due to trip changes.

Using the data above, $\Delta HC_{TRIP}$ = -18,192 + -3,561 + -16,189 + 7,490 = -30,452. Summarizing this result, the PATH project results in a net decrease in trip-related HC emissions of 30,452 grams per day. (Following the same methodology, total trip-related emission changes can also be determined for NOx and CO.)

Emission Effects -- STEP 2 (VMT Changes)

**Step 2** in the estimation of the emission effects for the PATH project involves calculating the effect of VMT changes on emissions. This step is broken down into four smaller steps (2a through 2d), which are outlined below.

**Step 2a** in the emission methodology involves estimating the distribution of VMT changes for the PATH project. These changes are calculated using the following formulas:

$$\gamma_{VMT,LDGV} = VMT_{LDGV} / (VMT_{LDGV} + VMT_{LDGT1})$$
$$\gamma_{VMT,LDGT1} = 1 - \gamma_{VMT,LDGV}$$

- In the formulas, $\gamma_{VMT,LDGV}$ is the fraction of *TCM-affected* VMT for light-duty gasoline vehicles (LDGVs), $\gamma_{TRIP,LDGT1}$ is the fraction of *TCM-affected* VMT for light-duty gasoline trucks (LDGT1s), $VMT_{LDGV}$ is the fraction of *total* VMT in the region for LDGVs, and $VMT_{LDGT1}$ is the fraction of *total* VMT in the region for LDGT1s. (Note: Most TCMs that can be analyzed using EPA's guidance document affect only LDGVs or LDGT1s. Thus, the sum of $\gamma_{VMT,LDGV}$ and $\gamma_{VMT,LDGT1}$ is typically equal to one.)

$VMT_{LDGV}$ and $VMT_{LDGT1}$ are assumed to equal 0.626 and 0.171, respectively. These values are the national average default values used in MOBILE for VMT mix.

Using the data above, $\gamma_{VMT,LDGV}$ = 0.626 / (0.626 + 0.171) = 0.785 and $\gamma_{VMT,LDGT1}$ = 1 - 0.785 = 0.215. Summarizing these results, 78.5% of the VMT affected by the PATH project is by LDGVs, and 21.5% is by LDGT1s.

**Step 2b** in the emission methodology involves estimating hot-stabilized exhaust emission changes for the PATH project. These changes are calculated using the following formulas:

$$\Delta HC_{STB,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * STB_{LDGV,HC,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * STB_{LDGT1,HC,P})$$
$$\Delta HC_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,HC,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,HC,OP})$$

$$\Delta NOx_{STB,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * STB_{LDGV,NOx,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * STB_{LDGT1,NOx,P})$$
$$\Delta NOx_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,NOx,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,NOx,OP})$$

$$\Delta CO_{STB,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * STB_{LDGV,CO,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * STB_{LDGT1,CO,P})$$
$$\Delta CO_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,CO,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,CO,OP})$$

- In the formulas, $\Delta HC_{STB,P}$, $\Delta NOx_{STB,P}$, and $\Delta CO_{STB,P}$ are the peak-period changes in hot-stabilized emissions for HC, NOx, and CO, respectively; and $\Delta HC_{STB,OP}$, $\Delta NOx_{STB,OP}$, and $\Delta CO_{STB,OP}$ are the off-peak changes in hot-stabilized emissions for HC, NOx, and CO, respectively. $STB_P$ is the hot-stabilized emission factor (in grams per mile) for each pollutant and vehicle class for the peak period (during which average vehicle speed is assumed to be 20 miles per hour), and $STB_{OP}$ is the hot-stabilized emission factor (in grams per mile) for each pollutant and vehicle class for the off-peak period (during which average vehicle speed is assumed to be 35 miles per hour). The other parameters in the formulas are defined in earlier steps of the methodology.

Using national default data from MOBILE, $\Delta HC_{STB,P} = (-19,187 * 0.785 * 1.23) + (-19,187 * 0.215 * 1.77) = -25,828$ and $\Delta HC_{STB,OP} = (-28,307 * 0.785 * 0.69) + (-28,307 * 0.215 * 0.94) = -21,053$. Summarizing these results, the PATH project results in a reduction in peak-period hot-stabilized HC exhaust emissions of 25,828 grams per day and a reduction in off-peak hot-stabilized HC exhaust emissions of 21,053 grams per day. (Following the same methodology, hot-stabilized exhaust emission changes can also be determined for NOx and CO.)

**Step 2c** in the emission methodology involves estimating VMT-related evaporative emission changes for the PATH project. These changes are calculated using the following formulas:

$$\Delta HC_{VEVP,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * VEVP_{LDGV,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * VEVP_{LDGT1,P})$$
$$\Delta HC_{VEVP,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * VEVP_{LDGV,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * VEVP_{LDGT1,OP})$$

- In the formulas, $\Delta HC_{VEVP,P}$ is the change in peak-period evaporative emissions, $\Delta HC_{VEVP,OP}$ is the change in off-peak evaporative emissions, and VEVP is the VMT-related evaporative emission factor (in grams per mile) for each vehicle class and time period (peak or off-peak). The other parameters in the formulas are defined in earlier steps of the methodology. (<u>Note</u>: Evaporative emissions are HC emissions only.)

Using national default data from MOBILE, $\Delta HC_{VEVP,P} = (-19,187 * 0.785 * 0.44) + (-19,187 * 0.215 * 0.53) = -8,814$ and $\Delta HC_{VEVP,OP} = (-28,307 * 0.785 * 0.34) + (-28,307 * 0.215 * 0.44) = -10,233$. Summarizing these results, the PATH project results in a reduction in peak-period evaporative emissions of 8,814 grams per day and a reduction in off-peak evaporative emissions of 10,233 grams per day.

**Step 2d** in the emission methodology involves calculating the total VMT-related emission changes for the PATH project. These changes are calculated using the following formulas:

$$\Delta HC_{VMT} = \Delta HC_{STB,P} + \Delta HC_{STB,OP} + \Delta HC_{VEVP,P} + \Delta HC_{VEVP,OP}$$
$$\Delta NOx_{VMT} = \Delta NOx_{STB,P} + \Delta NOx_{STB,OP}$$

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$$\Delta CO_{VMT} = \Delta CO_{STB,P} + \Delta CO_{STB,OP}$$

- In the formulas, $\Delta HC_{VMT}$, $\Delta NOx_{VMT}$, and $\Delta CO_{VMT}$ are the total changes in HC, NOx, and CO emissions, respectively, due to VMT changes.

Using the data above, $\Delta HC_{VMT}$ = -25,828 + -21,053 + -8,814 + -10,233 = -65,928. Summarizing this result, the PATH project results in a net decrease in VMT-related HC emissions of 65,928 grams per day. (Following the same methodology, total VMT-related emission changes can also be determined for NOx and CO.)

Emission Effects -- STEP 3 (Speed Changes)

**Step 3** in the estimation of the emission effects for the PATH project involves calculating the effect of speed changes on emissions. This step is broken down into four smaller steps (3a through 3d), which are outlined below.

**Step 3a** in the emission methodology involves estimating the speeds associated with the PATH project. These speeds are calculated using the following formulas:

$$SPEED_{P,TCM} = SPEED_{P,BASE} * (1 + \Delta SPD_P)$$
$$SPEED_{OP,TCM} = SPEED_{OP,BASE} * (1 + \Delta SPD_{OP})$$

- In the formulas, $SPEED_{P,TCM}$ is the peak-period speed after implementation of the TCM, $SPEED_{OP,TCM}$ is the off-peak speed after implementation of the TCM, $SPEED_{P,BASE}$ is the peak-period speed prior to implementation of the TCM, and $SPEED_{OP,BASE}$ is the off-peak speed prior to implementation of the TCM. The other parameters in the formulas are defined in earlier steps of the methodology.

Based on data for the national default fleet, $SPEED_{P,BASE}$ is assumed to be 20 miles per hour, and $SPEED_{OP,BASE}$ is assumed to be 35 miles per hour.

Using the data above, $SPEED_{P,TCM}$ = 20 * (1 + 0.0004) = 20.01 and $SPEED_{OP,TCM}$ = 35 * (1 + 0) = 35. Summarizing these results, peak-period speeds have slightly increased from 20 miles per hour to 20.01 miles per hour due to the PATH project. Off-peak speeds have not changed due to the project.

**Step 3b** in the emission methodology involves estimating the total VMT for the program area after implementation of the PATH project. These VMT figures are calculated using the following formulas:

$$VMT_{P,TCM} = TOTVMT_P + \Delta NETVMT_P$$
$$VMT_{OP,TCM} = TOTVMT_{OP} + \Delta NETVMT_{OP}$$

- In the formulas, $VMT_{P,TCM}$ is the total peak-period VMT in the program area after implementation of the TCM, and $VMT_{OP,TCM}$ is the total off-peak VMT in the program area after implementation of the TCM. The other parameters in the formulas are defined in earlier steps of the methodology.

Using data from Step 9 of the "Travel Activity Effects" section above, $VMT_{P,TCM}$ = 32,000,000 + -19,187 = 31,980,813 and $VMT_{OP,TCM}$ = 48,000,000 + -28,307 = 47,971,693. Summarizing these results, peak-period VMT has decreased from 32,000,000 miles per day to 31,980,813 miles per day due

to the PATH project. Off-peak VMT has decreased from 48,000,000 miles per day to 47,971,693 miles per day due to the project.

**Step 3c** in the emission methodology involves estimating peak-period and off-peak emission changes due to changes in vehicle speeds. These changes are calculated using the following formulas:

$$\Delta HC_{SPD,P} = VMT_{P,TCM} * (STB_{FLT,HC,P,TCM} + RNL_{FLT,P,TCM}) - VMT_{P,TCM} * (STB_{FLT,HC,P,BASE} + RNL_{FLT,P,BASE})$$
$$\Delta HC_{SPD,OP} = VMT_{OP,TCM} * (STB_{FLT,HC,OP,TCM} + RNL_{FLT,OP,TCM}) - VMT_{OP,TCM} * (STB_{FLT,HC,OP,BASE} + RNL_{FLT,OP,BASE})$$

$$\Delta NOx_{SPD,P} = VMT_{P,TCM} * (STB_{FLT,NOx,P,TCM} - STB_{FLT,NOx,P,BASE})$$
$$\Delta NOx_{SPD,OP} = VMT_{OP,TCM} * (STB_{FLT,NOx,OP,TCM} - STB_{FLT,NOx,OP,BASE})$$

$$\Delta CO_{SPD,P} = VMT_{P,TCM} * (STB_{FLT,CO,P,TCM} - STB_{FLT,CO,P,BASE})$$
$$\Delta CO_{SPD,OP} = VMT_{OP,TCM} * (STB_{FLT,CO,OP,TCM} - STB_{FLT,CO,OP,BASE})$$

- In the formulas, $\Delta HC_{SPD,P}$, $\Delta NOx_{SPD,P}$, and $\Delta CO_{SPD,P}$ are the peak-period changes in emissions for HC, NOx, and CO, respectively, due to a change in speeds; and $\Delta HC_{SPD,OP}$, $\Delta NOx_{SPD,OP}$, and $\Delta CO_{SPD,OP}$ are the off-peak changes in emissions for HC, NOx, and CO, respectively, due to a change in speeds. $STB_{FLT}$ is the fleet-wide hot-stabilized emission factor (in grams per mile) for each pollutant, time period (i.e., peak or off-peak), and scenario (i.e., base or TCM). $RNL_{FLT}$ is the fleet-wide running loss emission factor (in grams per mile) for each time period and scenario. The other parameters in the formulas are defined in earlier steps of the methodology.

Based on data showing the relationship between vehicle speed and emissions, this analysis assumes that the elasticity of $STB_{FLT}$ with respect to speed is -1 for HC, 0 for NOx, and -1 for CO. Thus, a 1% increase in speed is assumed to result in a 1% decrease in HC and CO emissions (on a grams per mile basis) and no change in NOx emissions. The elasticity of $RNL_{FLT}$ with respect to speed is also assumed to be -1.

Using national default data from MOBILE, $\Delta HC_{SPD,P} = 31,980,813 * (1.675 + 0.212)$ - $31,980,813 * (1.676 + 0.212) = -31,981$ and $\Delta HC_{SPD,OP} = 47,971,693 * (1.938 + 0.120) - 47,971,693$ $* (1.938 + 0.120) = 0$. Summarizing these results, the PATH project results in a decrease in speed-related HC emissions of 31,981 grams per day for the peak period but does not change speed-related HC emissions for the off-peak period. (Following the same methodology, the peak-period and off-peak emission changes due to changes in speeds can also be determined for NOx and CO.)

**Step 3d** in the emission methodology involves calculating the total speed-related emission changes for the PATH project. These changes are calculated using the following formulas:

$$\Delta HC_{SPD} = \Delta HC_{SPD,P} + \Delta HC_{SPD,OP}$$
$$\Delta NOx_{SPD} = \Delta NOx_{SPD,P} + \Delta NOx_{SPD,OP}$$
$$\Delta CO_{SPD} = \Delta CO_{SPD,P} + \Delta CO_{SPD,OP}$$

- In the formulas, $\Delta HC_{SPD}$, $\Delta NOx_{SPD}$, and $\Delta CO_{SPD}$ are the total changes in HC, NOx, and CO emissions, respectively, due to speed changes.

Using the data above, $\Delta HC_{SPD} = -31,981 + 0 = -31,981$. Summarizing this result, the PATH project results in a net decrease in speed-related HC emissions of 31,981 grams per day. (Following the same methodology, total speed-related emission changes can also be determined for NOx and CO.)

Emission Effects -- STEP 4 (Total)

**Step 4** in the estimation of the emission effects for the PATH project involves calculating the total changes in HC, NOx, and CO emissions.  These changes are calculated using the following formulas:

$$\Delta HC = \Delta HC_{TRIP} + \Delta HC_{VMT} + \Delta HC_{SPD}$$
$$\Delta NOx = \Delta NOx_{TRIP} + \Delta NOx_{VMT} + \Delta NOx_{SPD}$$
$$\Delta CO = \Delta CO_{TRIP} + \Delta CO_{VMT} + \Delta CO_{SPD}$$

- In the formulas, $\Delta HC$, $\Delta NOx$, and $\Delta CO$ are the total changes in HC, NOx, and CO emissions, respectively, due to the TCM program.

Using the data above, $\Delta HC$ = -30,452 + -65,928 + -31,981 = -128,361.  Summarizing this result, the PATH project results in a net decrease in HC emissions of 128,361 grams per day, or approximately 0.14 tons per day.  (Following the same methodology, total emission changes can also be determined for NOx and CO.)

**Example 3: Cleveland Walkway to Gateway**

General Description

The Cleveland Walkway to Gateway provides a link for transit riders arriving at Tower City Center, the main shopping and entertainment area of downtown Cleveland, to the Gateway Sports and Entertainment Complex. The climate-controlled walkway, which is about a quarter mile long, was designed in part to stimulate transit ridership in the metro area and relieve traffic congestion, especially during sporting events. The Greater Cleveland Regional Transport Authority determined that about 940,000 transit riders used the walkway during the 16-month period between April 1994 and August 1995.

(Note: Because the Walkway to Gateway is intended to link downtown shopping and entertainment areas with the Gateway complexes, which are primarily used for recreational activities (e.g., sporting events), this analysis assumes that the walkway has no effect (either directly or indirectly) on *work-related* trips, VMT, speeds, or emissions (commutes by Stadium/Arena employees are considered non-work trips for the purpose of this analysis). In addition, because events at the Gateway complex tend to occur during off-peak hours, the analysis assumes that the walkway has no effect on *peak period* trips, VMT, speeds, or emissions. Given these assumptions, this analysis excludes several of the formulas shown in EPA's TCM guidance and in some cases modifies formulas to reflect the nature of the travel activity and emissions effects from the Walkway to Gateway.)

Data Sources

- Interview with Joel Freilich, Director, Strategic Planning and Research, Greater Cleveland Regional Transit Authority, March 6, 1997.

- 1990 U.S. Census data.

- *1996 Statistical Abstract of the United States*.

- Texas Transportation Institute web page.

Phase 1: Travel Activity Effects

**Step 1** in the estimation of travel activity effects for the Walkway to Gateway involves an assessment of the potential trip effects from the program. For this TCM, these potential effects are calculated using the following *user-defined* formula:

$$PT = (N) / 487$$

**Phase 1: Effects on Travel Activity**
Step 1: Potential trip effects
Step 2: Direct work and non-work trip reductions
Step 3: Indirect work and non-work trip increases
Step 4: Peak and off-peak trip shifts
Step 5: Summation of distribution of trip effects among work peak, work off-peak, non-work peak, and non-work off-peak trips
Step 6: Peak and off-peak VMT changes due to reduced number of trips
Step 7: VMT changes due to reduced trip lengths
Step 8: Net VMT changes
Step 9: Peak and off-peak speed changes

- In the formula, PT is the potential effect on trips, and N is the number of transit riders who used the walkway between April 1994 and August 1995 (a period of 487 days) who would not have taken transit in the absence of the walkway.

The appropriate value for N is derived by "adjusting" the number of transit riders who used the walkway between April 1994 and August 1995 (i.e., 940,000) by the percentage of those riders who would not have taken transit in the absence of the walkway. Assuming that 70 percent of walkway users would not have taken transit, N = 0.70 * 940,000 = 658,000. (Note: The "70 percent" assumption for transit use is for illustrative purposes only. A more realistic assumption could be developed using surveys or expert judgment.) It should be noted that the Walkway is only open during events at Gateway. Therefore, actual emission reductions on a given day are more than the average derived here.

Using the data above, PT = (658,000) / 487 = 1,351. Thus, the potential number of trips reduced per day by the Walkway to Gateway is 1,351.

**Step 2** in the travel activity methodology involves estimating the *direct* work and non-work trip reductions from the Walkway to Gateway. Whereas the potential trip reductions calculated in Step 1 represent the total number of trips that *might* be reduced by a TCM program, direct trip reductions measure the number of trips that actually are reduced and, thus, can be less than potential trip reductions (e.g., if not all walkway users formerly drove alone to the Gateway complex). Direct trip reductions for the Walkway to Gateway are calculated using the following formulas:

$$\Delta TRIPS_D = \alpha * PT$$
$$\Delta TRIPS_{D,NW} = (1 - \omega) * \Delta TRIPS_D$$

- In the formulas, $\Delta TRIPS_D$ is the total direct trip reduction, PT is (as above) the potential trip reductions, $\Delta TRIPS_{D,NW}$ is the direct non-work trip reduction, $\alpha$ is the fraction of program participants who make a direct trip change, and $\omega$ is the fraction of trip effects that are work-related.

Because all trip reductions from the walkway are assumed to be non-work related, the TCM guidance call for the parameter $\omega$ to be set equal to 0.

For the Walkway to Gateway, $\alpha$ is defined as -(1 - DRIVTRAN) / AVO, where DRIVTRAN is the fraction of people who drive to public transit stations and AVO is average vehicle occupancy. This analysis assumes that 50 percent of transit riders using the walkway drive to public transit stations, and thus DRIVTRAN = 0.5. Average vehicle occupancy for trips to Gateway is estimated to be 1.5. Using these values for DRIVTRAN and AVO, $\alpha$ = -(1 - 0.5) / 1.5 = -0.33.

Using the data above, $\Delta TRIPS_D$ = -0.33 * 1,351 = -446 and $\Delta TRIPS_{D,NW}$ = (1 - 0) * -446 = -446. Summarizing these results, the Walkway to Gateway is responsible for directly reducing 446 trips per day, all of which are non-work related.

**Step 3** in the travel activity methodology involves estimating the actual *indirect* trip increases from the Walkway to Gateway. Indirect trip increases are secondary effects that typically result when vehicles normally used for other trips are left at home. For the Walkway to Gateway, these increases are calculated using the following formula:

$$\Delta TRIPS_{I,NW} = INC_{N,H} * -\Delta TRIPS_D / 2$$

- In the formula, $\Delta TRIPS_{I,NW}$ is the indirect non-work trip increase, and $INC_{N,H}$ is the rate of increased SOV non-work trip making by household members of TCM participants who leave their vehicles at home. The other parameter in the formula is defined in an earlier step of the methodology.

$INC_{N,H}$ is defined as NV * SHR * (SIZE - 1) * UNEMP * $TG_N$, where NV is the fraction of the population that does not own a vehicle (<u>Note</u>: This analysis interprets this parameter to mean the percentage of drivers without a vehicle, which is estimated as the percentage of vehicle-owning households in the program area that have only one vehicle.), SHR is the fraction of shared mode trips, SIZE is average household size, UNEMP is the fraction of the population that is not employed, and $TG_N$ is the non-work trip generation rate for SOV users. Based on 1990 U.S. Census data for Cuyahoga County, NV is assumed to be 45%, SHR is assumed to be 19%, and SIZE is assumed to be 2.39. Because the walkway is used almost entirely during evening hours, indirect trip increases do not depend on employment status, and thus UNEMP is set equal to 1. Finally, $TG_N$ is estimated to be 1.0, based on national default data indicating that the average person takes approximately 3 non-work trips per day and assuming that ⅓ of these trips are taken during the evening hours. Based on these numbers, $INC_{N,H}$ = 0.45 * 0.19 * (2.39 - 1) * 1 * 1 = 0.12.

Using the data above, $\Delta TRIPS_{I,NW}$ = 0.12 * -(-446) / 2 = 27. Thus, the Walkway to Gateway is indirectly responsible for an increase of 27 non-work trips per day.

**Step 4** in EPA's methodology for estimating travel activity effects of TCMs, which involves determining direct peak and off-peak period trip shifts, does not apply to projects such as the Walkway to Gateway.

**Step 5** in the travel activity methodology involves estimating the net trip changes from the Walkway to Gateway. These changes are calculated using the following formula:

$$\Delta NETRP_{NW,OP} = (1 - \omega) * \Delta TRIPS_{S,OP} + (1 - PK_{NW}) * (\Delta TRIPS_{D,NW} + \Delta TRIPS_{I,NW})$$

- In the formula, $\Delta NETRP_{NW,OP}$ is the net non-work trip change in the off-peak period, $\Delta TRIPS_{S,OP}$ is the change in off-peak period trips, and $PK_{NW}$ is the observed fraction of non-work trips during the peak period. The other parameters in the formula are defined in earlier steps of the methodology.

Because there are no trip shifts associated with transit improvements (see Step 4), $\Delta TRIPS_{S,OP}$ is equal to 0. Also, because direct and indirect trip effects from the Walkway to Gateway occur only at off-peak periods, EPA's TCM guidance calls for $PK_{NW}$ to be set equal to 0.

Using the data above, $\Delta NETRP_{NW,OP}$ = (1 - 0) * 0 + (1 - 0) * (-446 + 27) = -419. Thus, the Walkway to Gateway results in a net decrease of 419 off-peak non-work trips per day.

**Step 6** in the travel activity methodology involves estimating the off-peak VMT changes due to the trip changes from the Walkway to Gateway. These changes are calculated using the following formula:

$$\Delta VMT_{OP} = (\Delta NETRP_{W,OP} * DIST_W) + (\Delta NETRP_{NW,OP} * DIST_{NW})$$

- In the formula, $\Delta VMT_{OP}$ is the change in off-peak VMT due to trip changes, $DIST_W$ is the average VMT per trip for work trips, and $DIST_{NW}$ is the average

VMT per trip for non-work trips.  The other parameters in the formula are
defined in earlier steps of the methodology.

Because the Walkway to Gateway does not affect work trips, $\Delta NETRP_{W,OP}$ is equal to 0.  $DIST_{NW}$
is assumed to be 8 miles per trip for trips to the Gateway complex (based on information about transit trip
lengths provided by the Greater Cleveland Regional Transit Authority) and 8.1 miles per trip for all other
non-work trips (based on data from the *1996 Statistical Abstract of the United States*).

Using the data above, $\Delta VMT_{OP} = 0 + [(-446 * 8) + (27 * 8.1)] = -3,349$.  Thus, the Walkway
to Gateway reduces off-peak VMT by 3,349 miles per day due to trip changes.

**Step 7** in the travel activity methodology involves estimating the VMT changes due to trip length
changes resulting from the Walkway to Gateway.  These changes are calculated using the following
formula:

$$\Delta VMT_{L,NW} = \beta * PT * -(DIST_{NW} - DIST_{new})$$

- In the formula, $\Delta VMT_{L,NW}$ is the change in VMT due to trip length changes, $\beta$ is
  the fraction of program participants who change their trip length, $DIST_{NW}$ is the
  average length of a trip to the Gateway complex, and $DIST_{new}$ is the new trip
  length.  The other parameters in the formula are defined in earlier steps of the
  methodology.

Based on information in Table 2-10 of the TCM guidance,  $\beta$ is set equal to DRIVTRAN.
As noted in Step 2 above, DRIVTRAN = 0.5, and thus $\beta$ = 0.5.

As noted in Step 6 above, $DIST_{NW}$ for transit trips to Gateway is 8 miles.  That is, transit reduces
VMT by 8 miles per trip because transit stations tend to be located along the route from homes to
downtown Cleveland.  Therefore, regardless of the driving distance to transit stops, $DIST_{NW} - DIST_{new}$
= 8 miles.

Using the data above, $\Delta VMT_{L,NW} = 0.5 * 1,351 * -(8) = -5,404$.  Thus, the Walkway to Gateway
reduces VMT by 5,404 miles per day due to trip length changes.

**Step 8** in the travel activity methodology involves estimating the total off-peak VMT changes
resulting from the Walkway to Gateway.  These changes are calculated using the following formula:

$$\Delta NETVMT_{OP} = \Delta VMT_{OP} + (1 - PK_{NW}) * \Delta VMT_{L,NW}$$

- In the formula, $\Delta NETVMT_{OP}$ is the total change in off-peak VMT.  The other
  parameters in the formula are defined in earlier steps of the methodology.

Using the data above, $\Delta NETVMT_{OP} = -3,349 + (1 - 0) * -5,404 = -8,753$.  Thus, the Walkway
to Gateway reduces off-peak VMT by a total of 8,753 miles per day.

**Step 9** in the travel activity methodology involves estimating off-peak speed changes resulting
from the Walkway to Gateway.  These changes are calculated using the following formula:

$$\Delta SPD_{OP} = (\Delta NETVMT_{OP} / TOTVMT_{OP}) * \epsilon_{OP}$$

- In the formula, $\Delta SPD_{OP}$ is the change in off-peak speeds, $TOTVMT_{OP}$ is total off-peak VMT for the program area, and $\epsilon_{OP}$ is the elasticity of off-peak speed with respect to volume. The other parameter in the formula is defined in an earlier step of the methodology.

According to data from the Texas Transportation Institute, total VMT in metropolitan Cleveland is approximately 36 million miles per day. Assuming that 50 percent of travel activity occurs during off-peak periods, $TOTVMT_{OP}$ is approximately 18 million miles per day.

Post-event traffic is less congested as a result of increased tranit use. However, sufficient data is not available. Therefore, the parameter $\epsilon_{OP}$ is assumed to be 0, because changes in off-peak VMT do not usually affect vehicle speeds (i.e., due to a lack of congestion).

Using the data above, $\Delta SPD_{OP} = (-8,753 / 18,000,000) * 0 = 0$. Summarizing this result, the Walkway to Gateway has no effect on off-peak period speeds.

### Phase 2: Emission Effects -- STEP 1 (Trip Changes)

**Step 1** in the estimation of the emission effects for the Walkway to Gateway involves calculating the effect of trip changes on emissions. This step is broken down into seven smaller steps (1a through 1g), which are outlined below.

**Step 1a** in the emission methodology involves estimating the distribution of trip changes for the Walkway to Gateway. These changes are calculated using the following formulas:

$$\gamma_{TRIP,LDGV} = TRIP_{LDGV} / (TRIP_{LDGV} + TRIP_{LDGT1})$$
$$\gamma_{TRIP,LDGT1} = 1 - \gamma_{TRIP,LDGV}$$

**Phase 2: Effects on Emissions**

Step 1: Effect of trip changes on emissions
- 1a: Distribution of trip changes among vehicle types
- 1b: Changes in cold-start and hot-start trips
- 1c: Cold-start and hot-start emission factors by pollutant and vehicle type
- 1d: Cold-start and hot-start emission changes for the project
- 1e: Hot-soak emission changes
- 1f: Diurnal changes by vehicle type
- 1g: Summation of trip related emission changes

Step 2: Effect of VMT changes on emissions
- 2a: Distribution of VMT changes among vehicle types
- 2b: Hot-stabilized exhaust emission changes by vehicle type
- 2c: VMT-related evaporative emission changes
- 2d: Summation of VMT-related emission changes

Step 3: Emission effects due to speed changes
- 3a: Peak and off-peak speed after implementation
- 3b: Peak and off-peak VMT after implementation
- 3c: Peak and off-peak emissions changes due to changes in speeds
- 3d: Summation of speed related changes

Step 4: Summation of emission effects

- In the formulas, $\gamma_{TRIP,LDGV}$ is the fraction of *TCM-affected* trips taken by light-duty gasoline vehicles (LDGVs), $\gamma_{TRIP,LDGT1}$ is the fraction of *TCM-affected* trips taken by light-duty gasoline trucks (LDGT1s), $TRIP_{LDGV}$ is the fraction of *total* trips in the region taken by LDGVs, and $TRIP_{LDGT1}$ is the fraction of *total* trips in the region taken by LDGT1s.  (<u>Note</u>: Most TCMs that can be analyzed using EPA's guidance document affect only LDGVs or LDGT1s.  Thus, the sum of $\gamma_{TRIP,LDGV}$ and $\gamma_{TRIP,LDGT1}$ is typically equal to one.)

$TRIP_{LDGV}$ and $TRIP_{LDGT1}$ are assumed to equal 0.626 and 0.171, respectively.  These values are based on the national average default values used in MOBILE.

Using the data above, $\gamma_{TRIP,LDGV} = 0.626 / (0.626 + 0.171) = 0.785$ and $\gamma_{TRIP,LDGT1} = 1 - 0.785 = 0.215$.  Summarizing these results, 78.5% of the trips affected by the Walkway to Gateway are taken by LDGVs, and 21.5% are taken by LDGT1s.

**Step 1b** in the emission methodology involves calculating cold-start and hot-start trip changes for the Walkway to Gateway.  These changes are calculated using the following formulas:

$$\Delta TRIPS_{CST} = \gamma_{CST,W} * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) + \gamma_{CST, NW} * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP})$$
$$\Delta TRIPS_{HST} = (1 - \gamma_{CST,W}) * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) + (1 - \gamma_{CST,NW}) * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP})$$

- In the formulas, $\Delta TRIPS_{CST}$ is the number of cold-start trip changes, $\Delta TRIPS_{HST}$ is the number of hot-start trip changes, $\gamma_{CST,W}$ is the fraction of work trips begun in the cold-start mode, and $\gamma_{CST, NW}$ is the fraction of non-work trips begun in the cold-start mode.  The other parameters in the formulas are defined in earlier steps of the methodology.

Because work trips are mostly cold-start trips, the guidance calls for $\gamma_{CST,W}$ to be set equal to 1.  The guidance also suggests that $\gamma_{CST,NW}$ be set equal to 0.43, which is the default fraction of cold starts used in the Federal Test Procedure (FTP).

Using the data above, $\Delta TRIPS_{CST} = 1 * (0 + 0) + 0.43 * (0 + -419) = -180$ and $\Delta TRIPS_{HST} = (1 - 1) * (0 + 0) + (1 - 0.43) * (0 + -419) = -239$.  Summarizing these results, the Walkway to Gateway results in a reduction of 180 cold-start trips per day and a reduction of 239 hot-start trips per day.

**Step 1c** in the emission methodology involves determining cold-start and hot-start emission factors.  These changes are calculated *for a given pollutant and vehicle class* using the following formulas:

$$CST = (EXH_{100\%CST,26MPH} - EXH_{100\%STB,26MPH}) * 3.59$$
$$HST = (EXH_{100\%HST,26MPH} - EXH_{100\%STB,26MPH}) * 3.59$$

- In the formulas, CST is the cold-start emission factor in grams per trip, HST is the hot-start emission factor in grams per trip, and EXH is the MOBILE emission factor in grams per mile.  The 3.59 factor is the FTP driving cycle trip-start miles per trip, and 26 miles per hour is the speed for the start portion of the FTP driving cycle.  (<u>Note</u>: The subscripts on EXH refer to the operating conditions and speed at which MOBILE evaluates EXH.  For example, "100%CST,26MPH" indicates 100% cold-start operating mode at 26 miles per hour vehicle speed.)

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Using national default data from MOBILE, $CST_{LDGV,HC} = (2.55 - 0.95) * 3.59 = 5.74$ grams per trip, $CST_{LDGT1,HC} = (3.59 - 1.34) * 3.59 = 8.08$ grams per trip, $HST_{LDGV,HC} = (1.35 - 0.95) * 3.59 = 1.44$ grams per trip, and $HST_{LDGT1,HC} = (1.99 - 1.34) * 3.59 = 2.33$ grams per trip. (Following the same methodology, the cold-start and hot-start emission factors can also be determined for NOx and CO.)

**Step 1d** in the emission methodology involves determining cold-start and hot-start emission changes for the Walkway to Gateway. These changes are calculated using the following formulas:

$$\Delta HC_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,HC}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,HC})$$
$$\Delta HC_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,HC}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,HC})$$

$$\Delta NOx_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,NOx}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,NOx})$$
$$\Delta NOx_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,NOx}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,NOx})$$

$$\Delta CO_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,CO}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,CO})$$
$$\Delta CO_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,CO}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,CO})$$

- In the formulas, $\Delta HC_{CST}$, $\Delta NOx_{CST}$, and $\Delta CO_{CST}$ are the changes in cold-start emissions for HC, NOx, and CO, respectively; and $\Delta HC_{HST}$, $\Delta NOx_{HST}$, and $\Delta CO_{HST}$ are the changes in hot-start emissions for HC, NOx, and CO, respectively. The other parameters in the formulas are defined in earlier steps of the methodology.

Using national default data from MOBILE, $\Delta HC_{CST} = (-180 * 0.785 * 5.74) + (-180 * 0.215 * 8.08) = -1,124$ and $\Delta HC_{HST} = (-239 * 0.785 * 1.44) + (-239 * 0.215 * 2.33) = -390$. Summarizing these results, the Walkway to Gateway results in a reduction in cold-start HC emissions of 1,124 grams per day and a reduction in hot-start HC emissions of 390 grams per day. (Following the same methodology, the cold-start and hot-start emission changes can also be determined for NOx and CO.)

**Step 1e** in the emission methodology involves determining hot soak emission changes for the Walkway to Gateway. These changes are calculated using the following formula:

$$\Delta HC_{HSK} = (\Delta TRIPS_{TOTAL} * \gamma_{TRIP,LDGV} * HSK_{LDGV}) + (\Delta TRIPS_{TOTAL} * \gamma_{TRIP,LDGT1} * HSK_{LDGT1})$$

- In the formula, $\Delta HC_{HSK}$ is the change in hot soak emissions, $\Delta TRIPS_{TOTAL}$ is the total change in trips, and HSK is the hot soak emission factor in grams per trip. (<u>Note</u>: Hot soak emissions are HC emissions only.)

$\Delta TRIPS_{TOTAL} = \Delta NETRP_{W,P} + \Delta NETRP_{W,OP} + \Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP}$. Thus, $\Delta TRIPS_{TOTAL} = 0 + 0 + 0 + -419 = -419$.

Using national default data from MOBILE, $\Delta HC_{HSK} = (-419 * 0.785 * 3.06) + (-419 * 0.215 * 3.60) = -1,331$. Summarizing this result, the Walkway to Gateway results in a reduction in hot soak emissions of 1,331 grams per day.

**Step 1f** in the emission methodology involves determining diurnal emission changes for the Walkway to Gateway. These changes are calculated *for a given vehicle class* using the following formulas:

$$\Delta HC_{DNL,NW} = 0.676 * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP}) / TPD_{NW} * \gamma_{TRIP} * (WDI - MDI)$$

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$$\Delta HC_{DNL} = \Delta HC_{DNL,W,LDGV} + \Delta HC_{DNL,NW,LDGV} + \Delta HC_{DNL,W,LDGT1} + \Delta HC_{DNL,NW,LDGT1}$$

- In the formulas, $\Delta HC_{DNL,NW}$ is the change in diurnal emissions associated with non-work trips, and $\Delta HC_{DNL}$ is the total change in diurnal emissions. $TPD_{NW}$ is the number of non-work trips per day per vehicle. WDI is the weighted diurnal emission factor in grams, and MDI is the multi-day diurnal emission factor in grams. The other parameters in the formulas are defined in earlier steps of the methodology. (<u>Note</u>: Diurnal emissions are HC emissions only.)

$TPD_{NW}$ is assumed to equal to $TG_N$ from Step 3 of the "Travel Activity Effects" section above, and thus equals 1.0.

Using national default data from MOBILE, $\Delta HC_{DNL,NW,LDGV} = 0.676 * (0 + -419) / 1 * 0.785 * (3.30 - 6.04) = 609$, $\Delta HC_{DNL,NW,LDGT1} = 0.676 * (0 + -419) / 1 * 0.215 * (5.11 - 15.33) = 622$, and $\Delta HC_{DNL} = 0 + 609 + 0 + 622 = 1,231$. Summarizing these results, the Walkway to Gateway results in a net increase in diurnal emissions of 1,231 grams per day.

**Step 1g** in the emission methodology involves calculating the total trip-related emission changes for the Walkway to Gateway. These changes are calculated using the following formulas:

$$\Delta HC_{TRIP} = \Delta HC_{CST} + \Delta HC_{HST} + \Delta HC_{HSK} + \Delta HC_{DNL}$$
$$\Delta NOx_{TRIP} = \Delta NOx_{CST} + \Delta NOx_{HST}$$
$$\Delta CO_{TRIP} = \Delta CO_{CST} + \Delta CO_{HST}$$

- In the formulas, $\Delta HC_{TRIP}$, $\Delta NOx_{TRIP}$, and $\Delta CO_{TRIP}$ are the total changes in HC, NOx, and CO emissions, respectively, due to trip changes.

Using the data above, $\Delta HC_{TRIP} = -1,124 + -390 + -1,331 + 1,231 = -1,614$. Summarizing this result, the Walkway to Gateway results in a net decrease in trip-related HC emissions of 1,614 grams per day. (Following the same methodology, total trip-related emission changes can also be determined for NOx and CO.)

<u>Emission Effects -- STEP 2 (VMT Changes)</u>

**Step 2** in the estimation of the emission effects for the Walkway to Gateway involves calculating the effect of VMT changes on emissions. This step is broken down into four smaller steps (2a through 2d), which are outlined below.

**Step 2a** in the emission methodology involves estimating the distribution of VMT changes for the Walkway to Gateway. These changes are calculated using the following formulas:

$$\gamma_{VMT,LDGV} = VMT_{LDGV} / (VMT_{LDGV} + VMT_{LDGT1})$$
$$\gamma_{VMT,LDGT1} = 1 - \gamma_{VMT,LDGV}$$

- In the formulas, $\gamma_{VMT,LDGV}$ is the fraction of *TCM-affected* VMT for light-duty gasoline vehicles (LDGVs), $\gamma_{TRIP,LDGT1}$ is the fraction of *TCM-affected* VMT for light-duty gasoline trucks (LDGT1s), $VMT_{LDGV}$ is the fraction of *total* VMT in the region for LDGVs, and $VMT_{LDGT1}$ is the fraction of *total* VMT in the region for LDGT1s. (<u>Note</u>: Most TCMs that can be analyzed using EPA's guidance document affect only LDGVs or LDGT1s. Thus, the sum of $\gamma_{VMT,LDGV}$ and $\gamma_{VMT,LDGT1}$ is typically equal to one.)

VMT$_{LDGV}$ and VMT$_{LDGT1}$ are assumed to equal 0.626 and 0.171, respectively. These values are the national average default values used in MOBILE for VMT mix.

Using the data above, $\gamma_{VMT,LDGV} = 0.626 / (0.626 + 0.171) = 0.785$ and $\gamma_{VMT,LDGT1} = 1 - 0.785 = 0.215$. Summarizing these results, 78.5% of the VMT affected by the Walkway to Gateway is by LDGVs, and 21.5% is by LDGT1s.

**Step 2b** in the emission methodology involves estimating hot-stabilized exhaust emission changes for the Walkway to Gateway. These changes are calculated using the following formulas:

$$\Delta HC_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,HC,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,HC,OP})$$
$$\Delta NOx_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,NOx,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,NOx,OP})$$
$$\Delta CO_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,CO,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,CO,OP})$$

- In the formulas, $\Delta HC_{STB,OP}$, $\Delta NOx_{STB,OP}$, and $\Delta CO_{STB,OP}$ are the off-peak changes in hot-stabilized emissions for HC, NOx, and CO, respectively. $STB_{OP}$ is the hot-stabilized emission factor (in grams per mile) for each pollutant and vehicle class for the off-peak period (during which average vehicle speed is assumed to be 35 miles per hour). The other parameters in the formulas are defined in earlier steps of the methodology.

Using national default data from MOBILE, $\Delta HC_{STB,OP} = (-8,753 * 0.785 * 0.69) + (-8,753 * 0.215 * 0.94) = -6,510$. Summarizing this result, the Walkway to Gateway results in a reduction in off-peak hot-stabilized HC exhaust emissions of 6,510 grams per day. (Following the same methodology, hot-stabilized exhaust emission changes can also be determined for NOx and CO.)

**Step 2c** in the emission methodology involves estimating VMT-related evaporative emission changes for the Walkway to Gateway. These changes are calculated using the following formula:

$$\Delta HC_{VEVP,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * VEVP_{LDGV,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * VEVP_{LDGT1,OP})$$

- In the formula, $\Delta HC_{VEVP,OP}$ is the change in off-peak evaporative emissions, and VEVP is the VMT-related evaporative emission factor (in grams per mile) for each vehicle class. The other parameters in the formula are defined in earlier steps of the methodology. (<u>Note</u>: Evaporative emissions are HC emissions only.)

Using national default data from MOBILE, $\Delta HC_{VEVP,OP} = (-8,753 * 0.785 * 0.34) + (-8,753 * 0.215 * 0.44) = -3,164$. Summarizing this result, the Walkway to Gateway results in a reduction in off-peak evaporative emissions of 3,164 grams per day.

**Step 2d** in the emission methodology involves calculating the total VMT-related emission changes for the Walkway to Gateway. These changes are calculated using the following formulas:

$$\Delta HC_{VMT} = \Delta HC_{STB,P} + \Delta HC_{STB,OP} + \Delta HC_{VEVP,P} + \Delta HC_{VEVP,OP}$$
$$\Delta NOx_{VMT} = \Delta NOx_{STB,P} + \Delta NOx_{STB,OP}$$
$$\Delta CO_{VMT} = \Delta CO_{STB,P} + \Delta CO_{STB,OP}$$

- In the formulas, $\Delta HC_{VMT}$, $\Delta NOx_{VMT}$, and $\Delta CO_{VMT}$ are the total changes in HC, NOx, and CO emissions, respectively, due to VMT changes.

Using the data above, $\Delta HC_{VMT} = 0 + -6{,}510 + 0 + -3{,}164 = -9{,}674$.  Summarizing this result, the Walkway to Gateway results in a net decrease in VMT-related HC emissions of 9,674 grams per day. (Following the same methodology, total VMT-related emission changes can also be determined for NOx and CO.)

Emission Effects -- STEP 3 (Speed Changes)

**Step 3** in the estimation of the emission effects for the Walkway to Gateway involves calculating the effect of speed changes on emissions.  This step is not necessary because, as estimated in Step 9 above, the Walkway to Gateway has no effect on vehicle speeds.

Emission Effects -- STEP 4 (Total)

**Step 4** in the estimation of the emission effects for the Walkway to Gateway involves calculating the total changes in HC, NOx, and CO emissions.  These changes are calculated using the following formulas:

$$\Delta HC = \Delta HC_{TRIP} + \Delta HC_{VMT} + \Delta HC_{SPD}$$
$$\Delta NOx = \Delta NOx_{TRIP} + \Delta NOx_{VMT} + \Delta NOx_{SPD}$$
$$\Delta CO = \Delta CO_{TRIP} + \Delta CO_{VMT} + \Delta CO_{SPD}$$

- In the formulas, $\Delta HC$, $\Delta NOx$, and $\Delta CO$ are the total changes in HC, NOx, and CO emissions, respectively, due to the TCM program.

Using the data above, $\Delta HC = -1{,}614 + -9{,}674 + 0 = -11{,}288$.  Summarizing this result, the Walkway to Gateway results in a net decrease in HC emissions of 11,288 grams per day, or approximately 0.011 tons per day.  (Following the same methodology, total emission changes can also be determined for NOx and CO.)

**Example 4:    Brevard County Vanpool Service**

General Description

Brevard County, located along the eastern Florida coastline, has been operating an innovative vanpool program for more than 14 years.  The vanpool program, which provides commuter services and social service agency transportation needs to area residents, began in 1983 with six vans and by 1996 had grown to a total of 95 vans (44 of which are used for commuting).  The program is administered by Space Coast Area Transit (SCAT), in conjunction with a private, for-profit company called VPSI, Inc.

Data Sources

- Interview with Jim Leisenfelt, Program Director, SCAT, February 20, 1997.

- Interview with George Gaudy, VPSI, Inc., Brevard County, February 21, 1997.

- 1990 U.S. Census data.

- *1996 Statistical Abstract of the United States*.

- Texas Transportation Institute web page.

Phase 1: Travel Activity Effects

**Step 1** in the estimation of travel activity effects for the Brevard County Vanpool Service involves an assessment of the potential trip effects from the program.  For ridesharing programs, these potential effects are calculated using the following formula:

$$PT = N * F / D * 2$$

- In the formula, PT is the potential effect on trips, N is the number of participants in the ridesharing program, F is the frequency of participation (in days per week), and D is the average number of commute days per week.

**Phase 1: Effects on Travel Activity**
Step 1:  Potential trip effects
Step 2:  Direct work and non-work trip reductions
Step 3:  Indirect work and non-work trip increases
Step 4:  Peak and off-peak trip shifts
Step 5:  Summation of distribution of trip effects among work peak, work off-peak, non-work peak, and non-work off-peak trips
Step 6:  Peak and off-peak VMT changes due to reduced number of trips
Step 7:  VMT changes due to reduced trip lengths
Step 8:  Net VMT changes
Step 9:  Peak and off-peak speed changes

The appropriate value for N is determined from data obtained from interviews with program officials. A total of 44 vans are leased to commuters, and each van seats 11 people (1 driver and 10 passengers).  Thus, the greatest number of participants in the program at any one time is equal to 484 (i.e., 44 * 11).

This analysis assumes that participants use the vanpools for transportation to work every day. Thus, the value of F is assumed to be 5.

The value for D is 5, based on the fact that there are five workdays per week.

Using the data above, PT = 484 * 5 / 5 * 2 = 968. Thus, the potential number of trips reduced per day by the Brevard County Vanpool Service is 968.

**Step 2** in the travel activity methodology involves estimating the *direct* work and non-work trip reductions from the Brevard County Vanpool Service. Whereas the potential trip reductions calculated in Step 1 represent the total number of trips that *might* be reduced by a TCM program, direct trip reductions measure the number of trips that actually are reduced and, thus, can be less than potential trip reductions (e.g., if a participant in the program was previously part of a carpool). Direct trip reductions are calculated using the following formulas:

$$\Delta TRIPS_D = \alpha * PT$$
$$\Delta TRIPS_{D,W} = \omega * \Delta TRIPS_D$$
$$\Delta TRIPS_{D,NW} = (1 - \omega) * \Delta TRIPS_D$$

- In the formulas, $\Delta TRIPS_D$ is the total direct trip reduction, PT is (as above) the potential trip reductions, $\Delta TRIPS_{D,W}$ is the direct work trip reduction, $\Delta TRIPS_{D,NW}$ is the direct non-work trip reduction, $\alpha$ is the fraction of program participants who make a direct trip change, and $\omega$ is the fraction of trip effects that are work-related.

For ridesharing, $\alpha$ is defined as -[NOLD + NEW * (NCAR - 1) / NCAR] / AVO, where NOLD is the fraction of vanpoolers who join an existing vanpool and do not drive to a park and ride lot, NEW is the fraction of vanpoolers who form new vanpools and do not drive to a park and ride lot, NCAR is the average number of people in a vanpool, and AVO is average vehicle occupancy. Assuming that each vanpool is started by one person, all vans are full, and 5% of vanpoolers drive to park and ride lots, NOLD and NEW values are 0.864 and 0.086, respectively. NCAR is 11, which includes 1 driver and 10 passengers.

The value used for AVO is based on the following information from 1990 U.S. Census data for Brevard County: approximately 83% of work trips are in single occupancy vehicles (SOVs) (AVO = 1), approximately 13% of work trips are in carpools (AVO = 2.28), 2% of work trips are walking, 0.1% use buses (AVO assumed to be 15), and less than 2% of work trips are made using motorcycles, bicycles, and taxicabs combined. Thus, AVO = (0.83 + 0.13 + 0.02 + 0.001 + 0.02 ) / [(0.83 / 1) + (0.13 / 2.28) + (0.001 / 15)] = 1.13. Using the values for NOLD, NEW, NCAR, and AVO, $\alpha$ = -[0.864 + 0.086 * (11 - 1) / 11] / 1.13 = -0.83.

Table 2-5 in EPA's TCM guidance document indicates that, for ridesharing, the parameter $\omega$ is equal to 1. This is because ridesharing directly affects work trips only.

Using the data above, $\Delta TRIPS_D$ = -0.83 * 968 = -803, $\Delta TRIPS_{D,W}$ = 1 * -803 = -803 and $\Delta TRIPS_{D,NW}$ = (1 - 1) * -803 = 0. Summarizing these results, the Brevard County Vanpool Service is responsible for directly reducing 803 trips per day, all of which are work-related.

**Step 3** in the travel activity methodology involves estimating the actual *indirect* trip increases (for both work and non-work trips) from the Brevard County Vanpool Service. Indirect trip increases are secondary effects that typically result when vehicles normally used for commuting are left at home. These increases are calculated using the following formulas:

$$\Delta TRIPS_{I,W} = INC_{W,H} * -\Delta TRIPS_D / 2$$

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$$\Delta TRIPS_{I,NW} = INC_{N,H} * -\Delta TRIPS_D / 2$$

- In the formulas, $\Delta TRIPS_{I,W}$ is the indirect work trip increase, $\Delta TRIPS_{I,NW}$ is the indirect non-work trip increase, and $INC_{W,H}$ and $INC_{N,H}$ are the rates of increased SOV work and non-work trip making by household members of TCM participants who leave their vehicles at home. The other parameter in the formulas is defined in an earlier step of the methodology.

$INC_{W,H}$ is defined as NV * SHR * (SIZE - 1) * EMP * $TG_W$, where NV is the fraction of the population that does not own a vehicle (<u>Note</u>: This analysis interprets this parameter to mean the percentage of drivers without a vehicle, which is estimated as the percentage of vehicle-owning households in the program area that have only one vehicle.), SHR is the fraction of shared mode trips, SIZE is average household size, EMP is the fraction of the population that is employed, and $TG_W$ is the work trip generation rate for SOV users. Based on 1990 U.S. Census data for Brevard County, NV is assumed to be 41%, SHR is assumed to be 14%, SIZE is assumed to be 2.43, and EMP is assumed to be 58%. $TG_W$ is assumed to equal 2. Based on these numbers, $INC_{W,H} = 0.41 * 0.14 * (2.43 - 1) * 0.58 * 2 = 0.10$.

$INC_{N,H}$ = NV * SHR * (SIZE - 1) * UNEMP * $TG_N$, where NV, SHR, and SIZE are as defined above, UNEMP is the fraction of the population that is not employed, and $TG_N$ is the non-work trip generation rate for SOV users. UNEMP is simply (1 - EMP) and thus equals 42%. $TG_N$ is assumed to be the same as $TG_W$ (i.e., 2). Based on these numbers, $INC_{N,H} = 0.41 * 0.14 * (2.43 - 1) * 0.42 * 2 = 0.07$.

Using the data above, $\Delta TRIPS_{I,W} = 0.10 * -(-803) / 2 = 40$, and $\Delta TRIPS_{I,NW} = 0.07 * -(-803) / 2 = 28$. Summarizing these results, the Brevard County Vanpool Service is indirectly responsible for an increase of 40 work trips per day and 28 non-work trips per day.

**Step 4** in EPA's methodology for estimating travel activity effects of TCMs, which involves determining direct peak and off-peak period trip shifts, does not apply to ridesharing programs. Thus, Step 4 is not relevant to the analysis of the Brevard County Vanpool Service.

**Step 5** in the travel activity methodology involves estimating the net trip changes from the Brevard County Vanpool Service as distributed between work and non-work trips and peak and off-peak periods. These changes are calculated using the following formulas:

$$\Delta NETRP_{W,P} = \omega * \Delta TRIPS_{S,P} + PK_W * (\Delta TRIPS_{D,W} + \Delta TRIPS_{I,W})$$
$$\Delta NETRP_{W,OP} = \omega * \Delta TRIPS_{S,OP} + (1 - PK_W) * (\Delta TRIPS_{D,W} + \Delta TRIPS_{I,W})$$
$$\Delta NETRP_{NW,P} = (1 - \omega) * \Delta TRIPS_{S,P} + PK_{NW} * (\Delta TRIPS_{D,NW} + \Delta TRIPS_{I,NW})$$
$$\Delta NETRP_{NW,OP} = (1 - \omega) * \Delta TRIPS_{S,OP} + (1 - PK_{NW}) * (\Delta TRIPS_{D,NW} + \Delta TRIPS_{I,NW})$$

- In the formulas, $\Delta NETRP_{W,P}$ is the net work trip change in the peak period, $\Delta NETRP_{W,OP}$ is net work trip change in the off-peak period, $\Delta NETRP_{NW,P}$ is the net non-work trip change in the peak period, and $\Delta NETRP_{NW,OP}$ is the net non-work trip change in the off-peak period. $\Delta TRIPS_{S,P}$ is the change in peak period trips, and $\Delta TRIPS_{S,OP}$ is the change in off-peak period trips. $PK_W$ is the observed fraction of work trips during the peak period, and $PK_{NW}$ is the observed fraction of non-work trips during the peak period. The other parameters in the formulas are defined in earlier steps of the methodology.

Because there are no trip shifts associated with ridesharing (see Step 4), $\Delta TRIPS_{S,P}$ and $\Delta TRIPS_{S,OP}$ are each equal to 0.

The values used for $PK_W$ and $PK_{NW}$ are 0.6 and 0.3, respectively, based on an example shown in the TCM guidance document.

Using the data above, $\Delta NETRP_{W,P} = 0 + 0.6 * (-803 + 40) = -458$, $\Delta NETRP_{W,OP} = 0 + (1 - 0.6) * (-803 + 40) = -305$, $\Delta NETRP_{NW,P} = 0 + 0.3 * (0 + 28) = 8$, and $\Delta NETRP_{NW,OP} = 0 * (1 - 0.3) * (0 + 28) = 20$. Summarizing these results, the Brevard County Vanpool Service results in net decreases in peak and off-peak work trips of 458 per day and 305 per day, respectively. The program also results in increases in peak and off-peak non-work trips of 8 per day and 20 per day, respectively.

**Step 6** in the travel activity methodology involves estimating the peak and off-peak VMT changes due to the trip changes from the Brevard County Vanpool Service. These changes are calculated using the following formulas:

$$\Delta VMT_P = (\Delta NETRP_{W,P} * DIST_W) + (\Delta NETRP_{NW,P} * DIST_{NW})$$
$$\Delta VMT_{OP} = (\Delta NETRP_{W,OP} * DIST_W) + (\Delta NETRP_{NW,OP} * DIST_{NW})$$

- In the formulas, $\Delta VMT_P$ is the change in peak-period VMT due to trip changes, $\Delta VMT_{OP}$ is the change in off-peak VMT due to trip changes, $DIST_W$ is the average VMT per trip for work trips, and $DIST_{NW}$ is the average VMT per trip for non-work trips. The other parameters in the formulas are defined in earlier steps of the methodology.

$DIST_W$ is 50 miles per trip, as estimated by a vanpool service official. $DIST_{NW}$ is assumed to be 8.1 miles, based on data from the *1996 Statistical Abstract of the United States*.

Using the data above, $\Delta VMT_P = (-458 * 50) + (8 * 8.1) = -22,835$ and $\Delta VMT_{OP} = (-305 * 50) + (20 * 8.1) = -15,088$. Summarizing these results, the Brevard County Vanpool Service reduces peak-period VMT by 22,835 miles per day due to trip changes and reduces off-peak VMT by 15,088 miles per day due to trip changes.

**Step 7** in the travel activity methodology involves estimating the VMT changes due to trip length changes resulting from the Brevard County Vanpool Service. These changes are calculated using the following formula:

$$\Delta VMT_{L,W} = \beta * PT * -(DIST_W - DIST_{new})$$
$$\Delta VMT_{L,NW} = \beta * PT * -(DIST_{NW} - DIST_{new})$$

- In the formulas, $\Delta VMT_{L,W}$ is the change in VMT due to work trip length changes, $\Delta VMT_{L,NW}$ is the change in VMT due to non-work trip length changes, $\beta$ is fraction of program participants who change their trip length, and $DIST_{new}$ is the new work or non-work trip length. The other parameters in the formulas are defined in earlier steps of the methodology.

For ridesharing, the TCM guidance indicates that $\beta$ is equal to 1 - NOLD - NEW. As noted in Step 2 above, NOLD and NEW are 0.864 and 0.086, respectively. Thus, $\beta = 1 - 0.864 - 0.086 = 0.05$.

$DIST_{new}$ for work trips is assumed to be 5 miles. Because the Brevard County Vanpool Service does not directly affect non-work trips, $DIST_{new}$ for non-work trips is equal to $DIST_{NW}$.

Using the data above, $\Delta VMT_{L,W} = 0.05 * 968 * -(50 - 5) = -2,178$, and $\Delta VMT_{L,NW} = 0.05 * 968$

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\* -(8.1 - 8.1) = 0.  Summarizing these results, the Brevard County Vanpool Service reduces work-related VMT by 2,178 miles per day due to trip length changes but does not reduce non-work VMT due to trip length changes.

**Step 8** in the travel activity methodology involves estimating the total peak and off-peak VMT changes resulting from the Brevard County Vanpool Service.  These changes are calculated using the following formulas:

$$\Delta NETVMT_P = \Delta VMT_P + PK_W * \Delta VMT_{L,W} + PK_{NW} * \Delta VMT_{L,NW}$$
$$\Delta NETVMT_{OP} = \Delta VMT_{OP} + (1 - PK_W) * \Delta VMT_{L,W} + (1 - PK_{NW}) * \Delta VMT_{L,NW}$$

- In the formulas, $\Delta NETVMT_P$ is the total change in peak period VMT, and $\Delta NETVMT_{OP}$ is the total change in off-peak VMT.  The other parameters in the formulas are defined in earlier steps of the methodology.

Using the data above, $\Delta NETVMT_P = -22,835 + 0.6 * -2,178 + 0.3 * 0 = -24,142$ and $\Delta NETVMT_{OP} = -15,088 + (1 - 0.6) * -2,178 + (1 - 0.3) * 0 = -15,959$.  Summarizing these results, the Brevard County Vanpool Service reduces peak-period VMT by a total of 24,142 miles per day and off-peak VMT by a total of 15,959 miles per day.

**Step 9** in the travel activity methodology involves estimating peak and off-peak speed changes resulting from the Brevard County Vanpool Service.  These changes are calculated using the following formulas:

$$\Delta SPD_P = (\Delta NETVMT_P / TOTVMT_P) * \epsilon_P$$
$$\Delta SPD_{OP} = (\Delta NETVMT_{OP} / TOTVMT_{OP}) * \epsilon_{OP}$$

- In the formulas, $\Delta SPD_P$ is the percentage change in peak-period speeds, $\Delta SPD_{OP}$ is the change in off-peak speeds, $TOTVMT_P$ is total peak-period VMT for the program area, $TOTVMT_{OP}$ is total off-peak VMT for the program area, $\epsilon_P$ is the elasticity of peak-period speed with respect to volume, and $\epsilon_{OP}$ is the elasticity of off-peak speed with respect to volume.  The other parameters in the formulas are defined in earlier steps of the methodology.

Total VMT for Brevard County is assumed to be approximately 12 million miles per day.  This assumption is derived using data from the Texas Transportation Institute on VMT in the nearby Orlando area.  Assuming that 50 percent of travel activity occurs during peak periods and 50 percent occurs during off-peak periods, $TOTVMT_P$ and $TOTVMT_{OP}$ are each approximately 6 million miles per day.

The parameter $\epsilon_P$ is assumed to be -0.75, based on an example provided in the TCM guidance document.  The parameter $\epsilon_{OP}$ is assumed to be 0, because changes in off-peak VMT are not likely to affect vehicle speeds (i.e., due to a lack of congestion).

Using the data above, $\Delta SPD_P = -24,142 / 6,000,000 * -0.75 = 0.003$ and $\Delta SPD_{OP} = -15,959 / 6,000,000 * 0 = 0$.  Summarizing these results, the Brevard County Vanpool Service increases peak-period speeds by approximately 0.3% but has no effect on off-peak speeds.

Phase 2: Emission Effects -- STEP 1 (Trip Changes)

**Step 1** in the estimation of the emission effects for the Brevard County Vanpool Service involves calculating the effect of trip changes on emissions. This step is broken down into seven smaller steps (1a through 1g), which are outlined below.

**Step 1a** in the emission methodology involves estimating the distribution of trip changes for the Brevard County Vanpool Service. These changes are calculated using the following formulas:

$$\gamma_{TRIP,LDGV} = TRIP_{LDGV} / (TRIP_{LDGV} + TRIP_{LDGT1})$$
$$\gamma_{TRIP,LDGT1} = 1 - \gamma_{TRIP,LDGV}$$

- In the formulas, $\gamma_{TRIP,LDGV}$ is the fraction of *TCM-affected* trips taken by light-duty gasoline vehicles (LDGVs), $\gamma_{TRIP,LDGT1}$ is the fraction of *TCM-affected* trips taken by light-duty gasoline trucks (LDGT1s), $TRIP_{LDGV}$ is the fraction of *total* trips in the region taken by LDGVs, and $TRIP_{LDGT1}$ is the fraction of *total* trips in the region taken by LDGT1s. (Note: Most TCMs that can be analyzed using EPA's guidance document affect only LDGVs or LDGT1s. Thus, the sum of $\gamma_{TRIP,LDGV}$ and $\gamma_{TRIP,LDGT1}$ is typically equal to one.)

$TRIP_{LDGV}$ and $TRIP_{LDGT1}$ are assumed to equal 0.626 and 0.171, respectively. These values are based on the national average default values used in MOBILE.

Using the data above, $\gamma_{TRIP,LDGV} = 0.626 / (0.626 + 0.171) = 0.785$ and $\gamma_{TRIP,LDGT1} = 1 - 0.785 = 0.215$. Summarizing these results, 78.5% of the trips affected by the Brevard County Vanpool Service are taken by LDGVs, and 21.5% are taken by LDGT1s.

**Step 1b** in the emission methodology involves calculating cold-start and hot-start trip changes for the Brevard County Vanpool Service. These changes are calculated using the following formulas:

$$\Delta TRIPS_{CST} = \gamma_{CST,W} * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) + \gamma_{CST,NW} * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP})$$
$$\Delta TRIPS_{HST} = (1 - \gamma_{CST,W}) * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) + (1 - \gamma_{CST,NW}) * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP})$$

- In the formulas, $\Delta TRIPS_{CST}$ is the number of cold-start trip changes, $\Delta TRIPS_{HST}$ is the number of hot-start trip changes, $\gamma_{CST,W}$ is the fraction of work trips begun in the cold-start mode, and $\gamma_{CST,NW}$ is the fraction of non-work trips begun in the

**Phase 2: Effects on Emissions**

Step 1: Effect of trip changes on emissions
- 1a: Distribution of trip changes among vehicle types
- 1b: Changes in cold-start and hot-start trips
- 1c: Cold-start and hot-start emission factors by pollutant and vehicle type
- 1d: Cold-start and hot-start emission changes for the project
- 1e: Hot-soak emission changes
- 1f: Diurnal changes by vehicle type
- 1g: Summation of trip related emission changes

Step 2: Effect of VMT changes on emissions
- 2a: Distribution of VMT changes among vehicle types
- 2b: Hot-stabilized exhaust emission changes by vehicle type
- 2c: VMT-related evaporative emission changes
- 2d: Summation of VMT-related emission changes

Step 3: Emission effects due to speed changes
- 3a: Peak and off-peak speed after implementation
- 3b: Peak and off-peak VMT after implementation
- 3c: Peak and off-peak emissions changes due to changes in speeds
- 3d: Summation of speed related changes

Step 4: Summation of emission effects

cold-start mode. The other parameters in the formulas are defined in earlier steps of the methodology.

Because work trips are mostly cold-start trips, the guidance calls for $\gamma_{CST,W}$ to be set equal to 1. The guidance also suggests that $\gamma_{CST,NW}$ be set equal to 0.43, which is the default fraction of cold starts used in the Federal Test Procedure (FTP).

Using the data above, $\Delta TRIPS_{CST} = 1 * (-458 + -305) + 0.43 * (8 + 20) = -751$ and $\Delta TRIPS_{HST} = (1 - 1) * (-458 + -305) + (1 - 0.43) * (8 + 20) = 16$. Summarizing these results, the Brevard County Vanpool Service results in a reduction of 751 cold-start trips per day and an increase of 16 hot-start trips per day.

**Step 1c** in the emission methodology involves determining cold-start and hot-start emission factors. These changes are calculated *for a given pollutant and vehicle class* using the following formulas:

$$CST = (EXH_{100\%CST,26MPH} - EXH_{100\%STB,26MPH}) * 3.59$$
$$HST = (EXH_{100\%HST,26MPH} - EXH_{100\%STB,26MPH}) * 3.59$$

- In the formulas, CST is the cold-start emission factor in grams per trip, HST is the hot-start emission factor in grams per trip, and EXH is the MOBILE emission factor in grams per mile. The 3.59 factor is the FTP driving cycle trip-start miles per trip, and 26 miles per hour is the speed for the start portion of the FTP driving cycle. (Note: The subscripts on EXH refer to the operating conditions and speed at which MOBILE evaluates EXH. For example, "100%CST,26MPH" indicates 100% cold-start operating mode at 26 miles per hour vehicle speed.)

Using national default data from MOBILE, $CST_{LDGV,HC} = (2.55 - 0.95) * 3.59 = 5.74$ grams per trip, $CST_{LDGT1,HC} = (3.59 - 1.34) * 3.59 = 8.08$ grams per trip, $HST_{LDGV,HC} = (1.35 - 0.95) * 3.59 = 1.44$ grams per trip, and $HST_{LDGT1,HC} = (1.99 - 1.34) * 3.59 = 2.33$ grams per trip. (Following the same methodology, the cold-start and hot-start emission factors can also be determined for NOx and CO.)

**Step 1d** in the emission methodology involves determining cold-start and hot-start emission changes for the Brevard County Vanpool Service. These changes are calculated using the following formulas:

$$\Delta HC_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,HC}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,HC})$$
$$\Delta HC_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,HC}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,HC})$$

$$\Delta NOx_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,NOx}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,NOx})$$
$$\Delta NOx_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,NOx}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,NOx})$$

$$\Delta CO_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,CO}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,CO})$$
$$\Delta CO_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,CO}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,CO})$$

- In the formulas, $\Delta HC_{CST}$, $\Delta NOx_{CST}$, and $\Delta CO_{CST}$ are the changes in cold-start emissions for HC, NOx, and CO, respectively; and $\Delta HC_{HST}$, $\Delta NOx_{HST}$, and $\Delta CO_{HST}$ are the changes in hot-start emissions for HC, NOx, and CO, respectively. The other parameters in the formulas are defined in earlier steps of the methodology.

Using national default data from MOBILE, $\Delta HC_{CST} = (\text{-}751 * 0.785 * 5.74) + (\text{-}751 * 0.215 * 8.08) = \text{-}4,689$ and $\Delta HC_{HST} = (16 * 0.785 * 1.44) + (16 * 0.215 * 2.33) = 26$. Summarizing these results, the Brevard County Vanpool Service results in a reduction in cold-start HC emissions of 4,689 grams per day and an increase in hot-start HC emissions of 26 grams per day. (Following the same methodology, the cold-start and hot-start emission changes can also be determined for NOx and CO.)

**Step 1e** in the emission methodology involves determining hot soak emission changes for the Brevard County Vanpool Service. These changes are calculated using the following formula:

$$\Delta HC_{HSK} = (\Delta TRIPS_{TOTAL} * \gamma_{TRIP,LDGV} * HSK_{LDGV}) + (\Delta TRIPS_{TOTAL} * \gamma_{TRIP,LDGT1} * HSK_{LDGT1})$$

- In the formula, $\Delta HC_{HSK}$ is the change in hot soak emissions, $\Delta TRIPS_{TOTAL}$ is the total change in trips, and HSK is the hot soak emission factor in grams per trip. (<u>Note</u>: Hot soak emissions are HC emissions only.)

$$\Delta TRIPS_{TOTAL} = \Delta NETRP_{W,P} + \Delta NETRP_{W,OP} + \Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP}.$$
Thus, $\Delta TRIPS_{TOTAL} = \text{-}458 + \text{-}305 + 8 + 20 = \text{-}735$.

Using national default data from MOBILE, $\Delta HC_{HSK} = (\text{-}735 * 0.785 * 3.06) + (\text{-}735 * 0.215 * 3.60) = \text{-}2,334$. Summarizing this result, the Brevard County Vanpool Service results in a reduction in hot soak emissions of 2,334 grams per day.

**Step 1f** in the emission methodology involves determining diurnal emission changes for the Brevard County Vanpool Service. These changes are calculated *for a given vehicle class* using the following formulas:

$$\Delta HC_{DNL,W} = 0.676 * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) / TPD_W * \gamma_{TRIP} * (WDI - MDI)$$
$$\Delta HC_{DNL,NW} = 0.676 * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP}) / TPD_{NW} * \gamma_{TRIP} * (WDI - MDI)$$
$$\Delta HC_{DNL} = \Delta HC_{DNL,W,LDGV} + \Delta HC_{DNL,NW,LDGV} + \Delta HC_{DNL,W,LDGT1} + \Delta HC_{DNL,NW,LDGT1}$$

- In the formulas, $\Delta HC_{DNL,W}$ is the change in diurnal emissions associated with work trips, $\Delta HC_{DNL,NW}$ is the change in diurnal emissions associated with non-work trips, and $\Delta HC_{DNL}$ is the total change in diurnal emissions. $TPD_W$ is the number of work trips per day per vehicle, and $TPD_{NW}$ is the number of non-work trips per day per vehicle. WDI is the weighted diurnal emission factor in grams, and MDI is the multi-day diurnal emission factor in grams. The other parameters in the formulas are defined in earlier steps of the methodology. (<u>Note</u>: Diurnal emissions are HC emissions only.)

The value used for $TPD_W$ is 2, since a commuter makes typically makes two work trips per day (i.e., one trip from home to work, one trip from work to home). $TPD_{NW}$ is equal to $TG_N$ from Step 3 of the "Travel Activity Effects" section above, and thus equals 2.

Using national default data from MOBILE, $\Delta HC_{DNL,W,LDGV} = 0.676 * (\text{-}458 + \text{-}305) / 2 * 0.785 * (3.30 - 6.04) = 555$, $\Delta HC_{DNL,NW,LDGV} = 0.676 * (8 + 20) / 2 * 0.785 * (3.30 - 6.04) = \text{-}20$, $\Delta HC_{DNL,W,LDGT1} = 0.676 * (\text{-}458 + \text{-}305) / 2 * 0.215 * (5.11 - 15.33) = 567$, $\Delta HC_{DNL,NW,LDGT1} = 0.676 * (8 + 20) / 2 * 0.215 * (5.11 - 15.33) = \text{-}21$, and $\Delta HC_{DNL} = 555 + \text{-}20 + 567 + \text{-}21 = 1,081$. Summarizing these results, the Brevard County Vanpool Service results in an increase in diurnal emissions of 1,081 grams per day.

**Step 1g** in the emission methodology involves calculating the total trip-related emission changes for the Brevard County Vanpool Service. These changes are calculated using the following formulas:

$$\Delta HC_{TRIP} = \Delta HC_{CST} + \Delta HC_{HST} + \Delta HC_{HSK} + \Delta HC_{DNL}$$
$$\Delta NOx_{TRIP} = \Delta NOx_{CST} + \Delta NOx_{HST}$$
$$\Delta CO_{TRIP} = \Delta CO_{CST} + \Delta CO_{HST}$$

- In the formulas, $\Delta HC_{TRIP}$, $\Delta NOx_{TRIP}$, and $\Delta CO_{TRIP}$ are the total changes in HC, NOx, and CO emissions, respectively, due to trip changes.

Using the data above, $\Delta HC_{TRIP}$ = -4,689 + 26 + -2,334 + 1,081 = -5,916. Summarizing this result, the Brevard County Vanpool Service results in a net decrease in trip-related HC emissions of 5,916 grams per day. (Following the same methodology, total trip-related emission changes can also be determined for NOx and CO.)

Emission Effects -- STEP 2 (VMT Changes)

**Step 2** in the estimation of the emission effects for the Brevard County Vanpool Service involves calculating the effect of VMT changes on emissions. This step is broken down into four smaller steps (2a through 2d), which are outlined below.

**Step 2a** in the emission methodology involves estimating the distribution of VMT changes for the Brevard County Vanpool Service. These changes are calculated using the following formulas:

$$\gamma_{VMT,LDGV} = VMT_{LDGV} / (VMT_{LDGV} + VMT_{LDGT1})$$
$$\gamma_{VMT,LDGT1} = 1 - \gamma_{VMT,LDGV}$$

- In the formulas, $\gamma_{VMT,LDGV}$ is the fraction of *TCM-affected* VMT for light-duty gasoline vehicles (LDGVs), $\gamma_{TRIP,LDGT1}$ is the fraction of *TCM-affected* VMT for light-duty gasoline trucks (LDGT1s), $VMT_{LDGV}$ is the fraction of *total* VMT in the region for LDGVs, and $VMT_{LDGT1}$ is the fraction of *total* VMT in the region for LDGT1s. (<u>Note</u>: Most TCMs that can be analyzed using EPA's guidance document affect only LDGVs or LDGT1s. Thus, the sum of $\gamma_{VMT,LDGV}$ and $\gamma_{VMT,LDGT1}$ is typically equal to one.)

$VMT_{LDGV}$ and $VMT_{LDGT1}$ are assumed to equal 0.626 and 0.171, respectively. These values are the national average default values used in MOBILE for VMT mix.

Using the data above, $\gamma_{VMT,LDGV} = 0.626 / (0.626 + 0.171) = 0.785$ and $\gamma_{VMT,LDGT1} = 1 - 0.785 = 0.215$. Summarizing these results, 78.5% of the VMT affected by the Brevard County Vanpool Service is by LDGVs, and 21.5% is by LDGT1s.

**Step 2b** in the emission methodology involves estimating hot-stabilized exhaust emission changes for the Brevard County Vanpool Service. These changes are calculated using the following formulas:

$$\Delta HC_{STB,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * STB_{LDGV,HC,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * STB_{LDGT1,HC,P})$$
$$\Delta HC_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,HC,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,HC,OP})$$

$$\Delta NOx_{STB,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * STB_{LDGV,NOx,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * STB_{LDGT1,NOx,P})$$
$$\Delta NOx_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,NOx,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,NOx,OP})$$

$$\Delta CO_{STB,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * STB_{LDGV,CO,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * STB_{LDGT1,CO,P})$$
$$\Delta CO_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,CO,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,CO,OP})$$

- In the formulas, $\Delta HC_{STB,P}$, $\Delta NOx_{STB,P}$, and $\Delta CO_{STB,P}$ are the peak-period changes in hot-stabilized emissions for HC, NOx, and CO, respectively; and $\Delta HC_{STB,OP}$, $\Delta NOx_{STB,OP}$, and $\Delta CO_{STB,OP}$ are the off-peak changes in hot-stabilized emissions for HC, NOx, and CO, respectively. $STB_P$ is the hot-stabilized emission factor (in grams per mile) for each pollutant and vehicle class for the peak period (during which average vehicle speed is assumed to be 20 miles per hour), and $STB_{OP}$ is the hot-stabilized emission factor (in grams per mile) for each pollutant and vehicle class for the off-peak period (during which average vehicle speed is assumed to be 35 miles per hour). The other parameters in the formulas are defined in earlier steps of the methodology.

Using national default data from MOBILE, $\Delta HC_{STB,P} = (-24,142 * 0.785 * 1.23) + (-24,142 * 0.215 * 1.77) = -32,498$ and $\Delta HC_{STB,OP} = (-15,959 * 0.785 * 0.69) + (-15,959 * 0.215 * 0.94) = -11,870$. Summarizing these results, the Brevard County Vanpool Service results in a reduction in peak-period hot-stabilized HC exhaust emissions of 32,498 grams per day and a reduction in off-peak hot-stabilized HC exhaust emissions of 11,870 grams per day. (Following the same methodology, hot-stabilized exhaust emission changes can also be determined for NOx and CO.)

**Step 2c** in the emission methodology involves estimating VMT-related evaporative emission changes for the Brevard County Vanpool Service. These changes are calculated using the following formulas:

$$\Delta HC_{VEVP,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * VEVP_{LDGV,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * VEVP_{LDGT1,P})$$

$$\Delta HC_{VEVP,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * VEVP_{LDGV,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * VEVP_{LDGT1,OP})$$

- In the formulas, $\Delta HC_{VEVP,P}$ is the change in peak-period evaporative emissions, $\Delta HC_{VEVP,OP}$ is the change in off-peak evaporative emissions, and VEVP is the VMT-related evaporative emission factor (in grams per mile) for each vehicle class and time period (peak or off-peak). The other parameters in the formulas are defined in earlier steps of the methodology. (Note: Evaporative emissions are HC emissions only.)

Using national default data from MOBILE, $\Delta HC_{VEVP,P} = (-24,142 * 0.785 * 0.44) + (-24,142 * 0.215 * 0.53) = -11,090$ and $\Delta HC_{VEVP,OP} = (-15,959 * 0.785 * 0.34) + (-15,959 * 0.215 * 0.44) = -5,769$. Summarizing these results, the Brevard County Vanpool Service results in a reduction in peak-period evaporative emissions of 11,090 grams per day and a reduction in off-peak evaporative emissions of 5,769 grams per day.

**Step 2d** in the emission methodology involves calculating the total VMT-related emission changes for the Brevard County Vanpool Service. These changes are calculated using the following formulas:

$$\Delta HC_{VMT} = \Delta HC_{STB,P} + \Delta HC_{STB,OP} + \Delta HC_{VEVP,P} + \Delta HC_{VEVP,OP}$$
$$\Delta NOx_{VMT} = \Delta NOx_{STB,P} + \Delta NOx_{STB,OP}$$
$$\Delta CO_{VMT} = \Delta CO_{STB,P} + \Delta CO_{STB,OP}$$

- In the formulas, $\Delta HC_{VMT}$, $\Delta NOx_{VMT}$, and $\Delta CO_{VMT}$ are the total changes in HC, NOx, and CO emissions, respectively, due to VMT changes.

Using the data above, $\Delta HC_{VMT} = -32,498 + -11,870 + -11,090 + -5,769 = -61,227$. Summarizing this result, the Brevard County Vanpool Service results in a net decrease in VMT-related HC emissions of 61,227 grams per day. (Following the same methodology, total VMT-related emission changes can also be determined for NOx and CO.)

Emission Effects -- STEP 3 (Speed Changes)

**Step 3** in the estimation of the emission effects for the Brevard County Vanpool Service involves calculating the effect of speed changes on emissions. This step is broken down into four smaller steps (3a through 3d), which are outlined below.

**Step 3a** in the emission methodology involves estimating the speeds associated with the Brevard County Vanpool Service. These speeds are calculated using the following formulas:

$$SPEED_{P,TCM} = SPEED_{P,BASE} * (1 + \Delta SPD_P)$$
$$SPEED_{OP,TCM} = SPEED_{OP,BASE} * (1 + \Delta SPD_{OP})$$

- In the formulas, $SPEED_{P,TCM}$ is the peak-period speed after implementation of the TCM, $SPEED_{OP,TCM}$ is the off-peak speed after implementation of the TCM, $SPEED_{P,BASE}$ is the peak-period speed prior to implementation of the TCM, and $SPEED_{OP,BASE}$ is the off-peak speed prior to implementation of the TCM. The other parameters in the formulas are defined in earlier steps of the methodology.

Based on data for the national default fleet, $SPEED_{P,BASE}$ is assumed to be 20 miles per hour, and $SPEED_{OP,BASE}$ is assumed to be 35 miles per hour. (Note: These default assumptions for speeds

are likely to be unrealistic for Brevard County. The analysis might be similar, however, if more realistic values were used.)

Using the data above, $SPEED_{P,TCM} = 20 * (1 + 0.003) = 20.06$ and $SPEED_{OP,TCM} = 35 * (1 + 0) = 35$. Summarizing these results, peak-period speeds have slightly increased from 20 miles per hour to 20.06 miles per hour due to the Brevard County Vanpool Service. Off-peak speeds have not changed due to the service.

**Step 3b** in the emission methodology involves estimating the total VMT for the program area after implementation of the Brevard County Vanpool Service. These VMT figures are calculated using the following formulas:

$$VMT_{P,TCM} = TOTVMT_P + \Delta NETVMT_P$$
$$VMT_{OP,TCM} = TOTVMT_{OP} + \Delta NETVMT_{OP}$$

- In the formulas, $VMT_{P,TCM}$ is the total peak-period VMT in the program area after implementation of the TCM, and $VMT_{OP,TCM}$ is the total off-peak VMT in the program area after implementation of the TCM. The other parameters in the formulas are defined in earlier steps of the methodology.

Using data from Step 9 of the "Travel Activity Effects" section above, $VMT_{P,TCM} = 6,000,000 + -24,142 = 5,975,858$ and $VMT_{OP,TCM} = 6,000,000 + -15,959 = 5,984,041$. Summarizing these results, peak-period VMT has decreased from 6,000,000 miles per day to 5,975,858 miles per day due to the Brevard County Vanpool Service. Off-peak VMT has decreased from 6,000,000 miles per day to 5,984,041 miles per day due to the service.

**Step 3c** in the emission methodology involves estimating peak-period and off-peak emission changes due to changes in vehicle speeds. These changes are calculated using the following formulas:

$$\Delta HC_{SPD,P} = VMT_{P,TCM} * (STB_{FLT,HC,P,TCM} + RNL_{FLT,P,TCM}) - VMT_{P,TCM} * (STB_{FLT,HC,P,BASE} + RNL_{FLT,P,BASE})$$
$$\Delta HC_{SPD,OP} = VMT_{OP,TCM} * (STB_{FLT,HC,OP,TCM} + RNL_{FLT,OP,TCM}) - VMT_{OP,TCM} * (STB_{FLT,HC,OP,BASE} + RNL_{FLT,OP,BASE})$$

$$\Delta NOx_{SPD,P} = VMT_{P,TCM} * (STB_{FLT,NOx,P,TCM} - STB_{FLT,NOx,P,BASE})$$
$$\Delta NOx_{SPD,OP} = VMT_{OP,TCM} * (STB_{FLT,NOx,OP,TCM} - STB_{FLT,NOx,OP,BASE})$$

$$\Delta CO_{SPD,P} = VMT_{P,TCM} * (STB_{FLT,CO,P,TCM} - STB_{FLT,CO,P,BASE})$$
$$\Delta CO_{SPD,OP} = VMT_{OP,TCM} * (STB_{FLT,CO,OP,TCM} - STB_{FLT,CO,OP,BASE})$$

- In the formulas, $\Delta HC_{SPD,P}$, $\Delta NOx_{SPD,P}$, and $\Delta CO_{SPD,P}$ are the peak-period changes in emissions for HC, NOx, and CO, respectively, due to a change in speeds; and $\Delta HC_{SPD,OP}$, $\Delta NOx_{SPD,OP}$, and $\Delta CO_{SPD,OP}$ are the off-peak changes in emissions for HC, NOx, and CO, respectively, due to a change in speeds. $STB_{FLT}$ is the fleet-wide hot-stabilized emission factor (in grams per mile) for each pollutant, time period (i.e., peak or off-peak), and scenario (i.e., base or TCM). $RNL_{FLT}$ is the fleet-wide running loss emission factor (in grams per mile) for each time period and scenario. The other parameters in the formulas are defined in earlier steps of the methodology.

Based on data showing the relationship between vehicle speed and emissions, this analysis assumes that the elasticity of $STB_{FLT}$ with respect to speed is -1 for HC, 0 for NOx, and -1 for CO. Thus, a 1% increase in speed is assumed to result in a 1% decrease in HC and CO emissions (on a grams per mile basis) and no change in NOx emissions. The elasticity of $RNL_{FLT}$ with respect to speed is also assumed to be -1.

Using national default data from MOBILE, $\Delta HC_{SPD,P} = 5{,}975{,}858 * (1.671 + 0.211) - 5{,}975{,}858 * (1.676 + 0.212) = -35{,}855$ and $\Delta HC_{SPD,OP} = 5{,}984{,}041 * (1.938 + 0.120) - 5{,}984{,}041 * (1.938 + 0.120) = 0$. Summarizing these results, the Brevard County Vanpool Service results in a decrease in speed-related HC emissions of 35,855 grams per day for the peak period but does not change speed-related HC emissions for the off-peak period. (Following the same methodology, the peak-period and off-peak emission changes due to changes in speeds can also be determined for NOx and CO.)

**Step 3d** in the emission methodology involves calculating the total speed-related emission changes for the Brevard County Vanpool Service. These changes are calculated using the following formulas:

$$\Delta HC_{SPD} = \Delta HC_{SPD,P} + \Delta HC_{SPD,OP}$$
$$\Delta NOx_{SPD} = \Delta NOx_{SPD,P} + \Delta NOx_{SPD,OP}$$
$$\Delta CO_{SPD} = \Delta CO_{SPD,P} + \Delta CO_{SPD,OP}$$

- In the formulas, $\Delta HC_{SPD}$, $\Delta NOx_{SPD}$, and $\Delta CO_{SPD}$ are the total changes in HC, NOx, and CO emissions, respectively, due to speed changes.

Using the data above, $\Delta HC_{SPD} = -35{,}855 + 0 = -35{,}855$. Summarizing this result, the Brevard County Vanpool Service results in a net decrease in speed-related HC emissions of 35,855 grams per day. (Following the same methodology, total speed-related emission changes can also be determined for NOx and CO.)

Emission Effects -- STEP 4 (Total)

**Step 4** in the estimation of the emission effects for the Brevard County Vanpool Service involves calculating the total changes in HC, NOx, and CO emissions. These changes are calculated using the following formulas:

$$\Delta HC = \Delta HC_{TRIP} + \Delta HC_{VMT} + \Delta HC_{SPD}$$
$$\Delta NOx = \Delta NOx_{TRIP} + \Delta NOx_{VMT} + \Delta NOx_{SPD}$$
$$\Delta CO = \Delta CO_{TRIP} + \Delta CO_{VMT} + \Delta CO_{SPD}$$

- In the formulas, $\Delta HC$, $\Delta NOx$, and $\Delta CO$ are the total changes in HC, NOx, and CO emissions, respectively, due to the TCM program.

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Using the data above, $\Delta HC = -5,916 + -61,227 + -35,855 = -102,998$. Summarizing this result, the Brevard County Vanpool Service results in a net decrease in HC emissions of 102,998 grams per day, or approximately 0.11 tons per day. (Following the same methodology, total emission changes can also be determined for NOx and CO.)

**Example 5: Boulder HOP Shuttle Service**

General Description

In 1989, transportation planners in Boulder, Colorado designed the HOP shuttle service in response to commercial growth and the influx of traffic associated with the expansion. The goal of the program was to provide an alternative to SOV driving, and therefore preserve the quality of the air and prevent the construction of new roadways. The service was called the "HOP" because the name indicates the ease with which a passenger may "hop" around Boulder to meetings, school, shopping centers, etc. The service consists of six medium-size buses that circulate in two directions on a loop connecting the University of Colorado campus and retail district with downtown employment and retail areas and the Crossroads Mall area.

(Note: This analysis excludes the extra trips caused by the HOP shuttle buses themselves. Thus, the net effects on trips, VMT, speeds, and emissions will be smaller than shown here.)

Data Sources

• Interview with Penny Puskarich, Program Administrator, City of Boulder/Go Boulder, March 8, 1997.

• "HOP Shuttle Service Profile," prepared by City of Boulder, Colorado, June 25, 1996.

• 1990 U.S. Census data.

• *1996 Statistical Abstract of the United States*.

Phase 1: Travel Activity Effects

**Step 1** in the estimation of travel activity effects for the HOP service involves an assessment of the potential trip effects from the program. For this TCM, these potential effects are calculated using the following *user-defined* formula:

$$PT = N$$

• In the formula, PT is the potential effect on trips per day, and N is the number of TCM participants.

**Phase 1: Effects on Travel Activity**
Step 1:  Potential trip effects
Step 2:  Direct work and non-work trip reductions
Step 3:  Indirect work and non-work trip increases
Step 4:  Peak and off-peak trip shifts
Step 5:  Summation of distribution of trip effects among work peak, work off-peak, non-work peak, and non-work off-peak trips
Step 6:  Peak and off-peak VMT changes due to reduced number of trips
Step 7:  VMT changes due to reduced trip lengths
Step 8:  Net VMT changes
Step 9:  Peak and off-peak speed changes

The appropriate value of N is derived by dividing the number of people who use the HOP shuttle service each year by 307, the number of days per year the HOP Shuttle Service operates (it does not operate on Sundays and holidays). According to the "HOP Shuttle Service Profile," approximately 1.1 million riders used the service in 1996. Thus, PT = N = 1,100,000 / 307 = 3,583. Summarizing this result, the potential number of trips reduced per day by the HOP service is 3,583.

**Step 2** in the travel activity methodology involves estimating the *direct* work and non-work trip reductions from the HOP service. Whereas the potential trip reductions calculated in Step 1 represent

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the total number of trips that *might* be reduced by a TCM program, direct trip reductions measure the number of trips that actually are reduced and, thus, can be less than potential trip reductions (e.g., if a HOP rider was previously walking to his or her HOP destination). Direct trip reductions are calculated using the following formulas:

$$\Delta TRIPS_D = \alpha * PT$$
$$\Delta TRIPS_{D,W} = \omega * \Delta TRIPS_D$$
$$\Delta TRIPS_{D,NW} = (1 - \omega) * \Delta TRIPS_D$$

- In the formulas, $\Delta TRIPS_D$ is the total direct trip reduction, PT is (as above) the potential trip reductions, $\Delta TRIPS_{D,W}$ is the direct work trip reduction, $\Delta TRIPS_{D,NW}$ is the direct non-work trip reduction, $\alpha$ is the fraction of program participants who make a direct trip change, and $\omega$ is the fraction of trip effects that are work-related.

For transit improvements, $\alpha$ is defined as -1 / AVO, where AVO is average vehicle occupancy. Assuming average vehicle occupancy for non-work trips is the same as work trips, the value used for AVO is based on the following information from 1990 U.S. Census data for the City of Boulder: approximately 65% of work trips are in single occupancy vehicles (SOVs) (AVO = 1), approximately 10% of work trips are in carpools (AVO = 2.3), 11% of work trips are walking, 6% use buses (AVO assumed to be 15), and less than 8% of work trips are made using other means. Thus, AVO = (0.65 + 0.1 + 0.11 + 0.06 + 0.08 ) / [(0.65 / 1) + (0.1 / 2.3) + (0.06 / 15)] = 1.43. Using this value for AVO, $\alpha$ = -1 / 1.43 = -0.7.

Based on survey results from the "HOP Shuttle Service Profile," approximately 20% of HOP riders use the service for work travel. Thus, the parameter $\omega$ is equal to 0.2.

Using the data above, $\Delta TRIPS_D$ = -0.7 * 3,583 = -2,508, $\Delta TRIPS_{D,W}$ = 0.2 * -2,508 = -502, and $\Delta TRIPS_{D,NW}$ = (1 - 0.2) * -2,508 = -2,006. Summarizing these results, the HOP service is responsible for directly reducing 502 work trips per day and 2,006 non-work trips per day.

**Step 3** in the travel activity methodology involves estimating the actual *indirect* trip increases (for both work and non-work trips) from the HOP service. Indirect trip increases are secondary effects that typically result when vehicles normally used for commuting are left at home. These increases are calculated using the following formulas:

$$\Delta TRIPS_{I,W} = INC_{W,H} * -\Delta TRIPS_D / 2$$
$$\Delta TRIPS_{I,NW} = INC_{N,H} * -\Delta TRIPS_D / 2$$

- In the formulas, $\Delta TRIPS_{I,W}$ is the indirect work trip increase, $\Delta TRIPS_{I,NW}$ is the indirect non-work trip increase, and $INC_{W,H}$ and $INC_{N,H}$ are the rates of increased SOV work and non-work trip making by household members of TCM participants who leave their vehicles at home. The other parameter in the formulas is defined in an earlier step of the methodology.

$INC_{W,H}$ is defined as NV * SHR * (SIZE - 1) * EMP * $TG_W$, where NV is the fraction of the population that does not own a vehicle (Note: This analysis interprets this parameter to mean the percentage of drivers without a vehicle, which is estimated as the percentage of vehicle-owning households in the program area that have only one vehicle.), SHR is the fraction of shared mode trips, SIZE is average household size, EMP is the fraction of the population that is employed, and $TG_W$ is the work trip generation rate for SOV users. Based on 1990 U.S. Census data for the City of Boulder, NV

is assumed to be 34%, SHR is assumed to be 16%, SIZE is assumed to be 2.45, and EMP is assumed to be 70%. $TG_W$ is assumed to equal 2. Based on these numbers, $INC_{W,H} = 0.34 * 0.16 * (2.45 - 1) * 0.7 * 2 = 0.11$.

$INC_{N,H} = NV * SHR * (SIZE - 1) * UNEMP * TG_N$, where NV, SHR, and SIZE are as defined above, UNEMP is the fraction of the population that is not employed, and $TG_N$ is the non-work trip generation rate for SOV users. UNEMP is simply (1 - EMP) and thus equals 30%. $TG_N$ is assumed to be the same as $TG_W$ (i.e., 2). Based on these numbers, $INC_{N,H} = 0.34 * 0.16 * (2.45 - 1) * 0.3 * 2 = 0.05$.

Using the data above, $\Delta TRIPS_{I,W} = 0.11 * -(-2,508) / 2 = 138$, and $\Delta TRIPS_{I,NW} = 0.05 * -(-2,508) / 2 = 63$. Summarizing these results, the HOP service is indirectly responsible for an increase of 138 work trips per day and 63 non-work trips per day.

**Step 4** in EPA's methodology for estimating travel activity effects of TCMs, which involves determining direct peak and off-peak period trip shifts, does not apply to transit improvements. Thus, Step 4 is not relevant to the analysis of the HOP service.

**Step 5** in the travel activity methodology involves estimating the net trip changes from the HOP service as distributed between work and non-work trips and peak and off-peak periods. These changes are calculated using the following formulas:

$$\Delta NETRP_{W,P} = \omega * \Delta TRIPS_{S,P} + PK_W * (\Delta TRIPS_{D,W} + \Delta TRIPS_{I,W})$$
$$\Delta NETRP_{W,OP} = \omega * \Delta TRIPS_{S,OP} + (1 - PK_W) * (\Delta TRIPS_{D,W} + \Delta TRIPS_{I,W})$$
$$\Delta NETRP_{NW,P} = (1 - \omega) * \Delta TRIPS_{S,P} + PK_{NW} * (\Delta TRIPS_{D,NW} + \Delta TRIPS_{I,NW})$$
$$\Delta NETRP_{NW,OP} = (1 - \omega) * \Delta TRIPS_{S,OP} + (1 - PK_{NW}) * (\Delta TRIPS_{D,NW} + \Delta TRIPS_{I,NW})$$

- In the formulas, $\Delta NETRP_{W,P}$ is the net work trip change in the peak period, $\Delta NETRP_{W,OP}$ is net work trip change in the off-peak period, $\Delta NETRP_{NW,P}$ is the net non-work trip change in the peak period, and $\Delta NETRP_{NW,OP}$ is the net non-work trip change in the off-peak period. $\Delta TRIPS_{S,P}$ is the change in peak period trips, and $\Delta TRIPS_{S,OP}$ is the change in off-peak period trips. $PK_W$ is the observed fraction of work trips during the peak period, and $PK_{NW}$ is the observed fraction of non-work trips during the peak period. The other parameters in the formulas are defined in earlier steps of the methodology.

Because there are no trip shifts associated with transit improvements (see Step 4), $\Delta TRIPS_{S,P}$ and $\Delta TRIPS_{S,OP}$ are each equal to 0.

The values used for $PK_W$ and $PK_{NW}$ are 0.6 and 0.3, respectively, based on an example shown in the TCM guidance document.

Using the data above, $\Delta NETRP_{W,P} = 0 + 0.6 * (-502 + 138) = -218$, $\Delta NETRP_{W,OP} = 0 + (1 - 0.6) * (-502 + 138) = -146$, $\Delta NETRP_{NW,P} = 0 + 0.3 * (-2,006 + 63) = -583$, and $\Delta NETRP_{NW,OP} = 0 * (1 - 0.3) * (-2,006 + 63) = -1,360$. Summarizing these results, the HOP service results in net decreases in peak and off-peak work trips of 218 per day and 146 per day, respectively. The service also results in decreases in peak and off-peak non-work trips of 583 per day and 1,360 per day, respectively.

**Step 6** in the travel activity methodology involves estimating the peak and off-peak VMT changes due to the trip changes from the HOP service. These changes are calculated using the following formulas:

$$\Delta VMT_P = (\Delta NETRP_{W,P} * DIST_W) + (\Delta NETRP_{NW,P} * DIST_{NW})$$
$$\Delta VMT_{OP} = (\Delta NETRP_{W,OP} * DIST_W) + (\Delta NETRP_{NW,OP} * DIST_{NW})$$

- In the formulas, $\Delta VMT_P$ is the change in peak-period VMT due to trip changes, $\Delta VMT_{OP}$ is the change in off-peak VMT due to trip changes, $DIST_W$ is the average VMT per trip for work trips, and $DIST_{NW}$ is the average VMT per trip for non-work trips. The other parameters in the formulas are defined in earlier steps of the methodology.

The total length of the Hop Shuttle Service route is six miles. The average trip, according to Go Boulder officials is two miles. Hence, both $DIST_W$ and $DIST_{NW}$ are assumed to be 2 miles.

Using the data above, $\Delta VMT_P = (-218 * 2) + (-583 * 2) = -1,602$ and $\Delta VMT_{OP} = (-146 * 2) + (-1,360 * 2) = -3,012$. Summarizing these results, the HOP service reduces peak-period VMT by 1,602 miles per day due to trip changes and reduces off-peak VMT by 3,012 miles per day due to trip changes.

**Step 7** in the travel activity methodology involves estimating the VMT changes due to trip length changes resulting from the HOP service. These changes are calculated using the following formulas:

$$\Delta VMT_{L,W} = \beta * PT * -(DIST_W - DIST_{new})$$
$$\Delta VMT_{L,NW} = \beta * PT * -(DIST_{NW} - DIST_{new})$$

- In the formulas, $\Delta VMT_{L,W}$ is the change in VMT due to work trip length changes, $\Delta VMT_{L,NW}$ is the change in VMT due to non-work trip length changes, $\beta$ is fraction of program participants who change their trip length, and $DIST_{new}$ is the new work or non-work trip length. The other parameters in the formulas are defined in earlier steps of the methodology.

Although it is conceivable that people may drive to a HOP stop to access the shuttle, this analysis assumes that no HOP users do so. Thus, both $\beta$ and $DIST_{new}$ are set equal to 0.

Using the data above, $\Delta VMT_{L,W} = 0 * 3,583 * -(2 - 0) = 0$, and $\Delta VMT_{L,NW} = 0 * 3,583 * -(2 - 0) = 0$. Summarizing these results, the HOP service does not reduce VMT through changes in trip lengths.

**Step 8** in the travel activity methodology involves estimating the total peak and off-peak VMT changes resulting from the HOP service. These changes are calculated using the following formulas:

$$\Delta NETVMT_P = \Delta VMT_P + PK_W * \Delta VMT_{L,W} + PK_{NW} * \Delta VMT_{L,NW}$$
$$\Delta NETVMT_{OP} = \Delta VMT_{OP} + (1 - PK_W) * \Delta VMT_{L,W} + (1 - PK_{NW}) * \Delta VMT_{L,NW}$$

- In the formulas, $\Delta NETVMT_P$ is the total change in peak period VMT, and $\Delta NETVMT_{OP}$ is the total change in off-peak VMT. The other parameters in the formulas are defined in earlier steps of the methodology.

Using the data above, $\Delta NETVMT_P = -1,602 + 0.6 * 0 + 0.3 * 0 = -1,602$ and $\Delta NETVMT_{OP} = -3,012 + (1 - 0.6) * 0 + (1 - 0.3) * 0 = -3,012$. Summarizing these results, the HOP service reduces peak-period VMT by a total of 1,602 miles per day and off-peak VMT by a total of 3,012 miles per day.

**Step 9** in the travel activity methodology involves estimating peak and off-peak speed changes resulting from the HOP service. These changes are calculated using the following formulas:

$$\Delta SPD_P = (\Delta NETVMT_P / TOTVMT_P) * \epsilon_P$$
$$\Delta SPD_{OP} = (\Delta NETVMT_{OP} / TOTVMT_{OP}) * \epsilon_{OP}$$

- In the formulas, $\Delta SPD_P$ is the percentage change in peak-period speeds, $\Delta SPD_{OP}$ is the change in off-peak speeds, $TOTVMT_P$ is total peak-period VMT for the program area, $TOTVMT_{OP}$ is total off-peak VMT for the program area, $\epsilon_P$ is the elasticity of peak-period speed with respect to volume, and $\epsilon_{OP}$ is the elasticity of off-peak speed with respect to volume. The other parameters in the formulas are defined in earlier steps of the methodology.

Total VMT for the City of Boulder is assumed to be approximately 2 million miles per day. This assumption is derived using data from the Texas Transportation Institute on VMT in the nearby Denver area. Assuming that 50 percent of travel activity occurs during peak periods and 50 percent occurs during off-peak periods, $TOTVMT_P$ and $TOTVMT_{OP}$ are each approximately 1 million miles per day.

The parameter $\epsilon_P$ is assumed to be -0.75, based on an example provided in the TCM guidance document. The parameter $\epsilon_{OP}$ is assumed to be 0, because changes in off-peak VMT are not likely to affect vehicle speeds (i.e., due to a lack of congestion).

Using the data above, $\Delta SPD_P = -1{,}602 / 1{,}000{,}000 * -0.75 = 0.001$ and $\Delta SPD_{OP} = -3{,}012 /1{,}000{,}000 * 0 = 0$. Summarizing these results, the HOP service increases peak-period speeds by approximately 0.1% but has no effect on off-peak speeds.

Phase 2: Emission Effects -- STEP 1 (Trip Changes)

**Step 1** in the estimation of the emission effects for the HOP service involves calculating the effect of trip changes on emissions. This step is broken down into seven smaller steps (1a through 1g), which are outlined below.

**Step 1a** in the emission methodology involves estimating the distribution of trip changes for the HOP service. These changes are calculated using the following formulas:

$$\gamma_{TRIP,LDGV} = TRIP_{LDGV} / (TRIP_{LDGV} + TRIP_{LDGT1})$$
$$\gamma_{TRIP,LDGT1} = 1 - \gamma_{TRIP,LDGV}$$

- In the formulas, $\gamma_{TRIP,LDGV}$ is the fraction of *TCM-affected* trips taken by light-duty gasoline vehicles (LDGVs), $\gamma_{TRIP,LDGT1}$ is the fraction of *TCM-affected* trips taken by light-duty gasoline trucks (LDGT1s), $TRIP_{LDGV}$ is the fraction of *total* trips in the region taken by LDGVs, and $TRIP_{LDGT1}$ is the fraction of *total* trips in the region taken by LDGT1s. (Note: Most TCMs that can be analyzed using EPA's guidance document affect only LDGVs or LDGT1s. Thus, the sum of $\gamma_{TRIP,LDGV}$ and $\gamma_{TRIP,LDGT1}$ is typically equal to one.)

**Phase 2: Effects on Emissions**
Step 1: Effect of trip changes on emissions
- 1a: Distribution of trip changes among vehicle types
- 1b: Changes in cold-start and hot-start trips
- 1c: Cold-start and hot-start emission factors by pollutant and vehicle type
- 1d: Cold-start and hot-start emission changes for the project
- 1e: Hot-soak emission changes
- 1f: Diurnal changes by vehicle type
- 1g: Summation of trip related emission changes

Step 2: Effect of VMT changes on emissions
- 2a: Distribution of VMT changes among vehicle types
- 2b: Hot-stabilized exhaust emission changes by vehicle type
- 2c: VMT-related evaporative emission changes
- 2d: Summation of VMT-related emission changes

Step 3: Emission effects due to speed changes
- 3a: Peak and off-peak speed after implementation
- 3b: Peak and off-peak VMT after implementation
- 3c: Peak and off-peak emissions changes due to changes in speeds
- 3d: Summation of speed related changes

Step 4: Summation of emission effects

$TRIP_{LDGV}$ and $TRIP_{LDGT1}$ are assumed to equal 0.626 and 0.171, respectively. These values are based on the national average default values used in MOBILE.

Using the data above, $\gamma_{TRIP,LDGV} = 0.626 / (0.626 + 0.171) = 0.785$ and $\gamma_{TRIP,LDGT1} = 1 - 0.785 = 0.215$. Summarizing these results, 78.5% of the trips affected by the HOP service are taken by LDGVs, and 21.5% are taken by LDGT1s.

**Step 1b** in the emission methodology involves calculating cold-start and hot-start trip changes for the HOP service. These changes are calculated using the following formulas:

$$\Delta TRIPS_{CST} = \gamma_{CST,W} * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) + \gamma_{CST,NW} * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP})$$
$$\Delta TRIPS_{HST} = (1 - \gamma_{CST,W}) * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) + (1 - \gamma_{CST,NW}) * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP})$$

- In the formulas, $\Delta TRIPS_{CST}$ is the number of cold-start trip changes, $\Delta TRIPS_{HST}$ is the number of hot-start trip changes, $\gamma_{CST,W}$ is the fraction of work trips begun in the cold-start mode, and $\gamma_{CST,NW}$ is the fraction of non-work trips begun in the

cold-start mode. The other parameters in the formulas are defined in earlier steps of the methodology.

Because work trips are mostly cold-start trips, the guidance calls for $\gamma_{CST,W}$ to be set equal to 1. The guidance also suggests that $\gamma_{CST,NW}$ be set equal to 0.43, which is the default fraction of cold starts used in the Federal Test Procedure (FTP).

Using the data above, $\Delta TRIPS_{CST} = 1 * (-218 + -146) + 0.43 * (-583 + -1{,}360) = -1{,}200$ and $\Delta TRIPS_{HST} = (1 - 1) * (-218 + -146) + (1 - 0.43) * (-583 + -1{,}360) = -1{,}108$. Summarizing these results, the HOP service results in a reduction of 1,200 cold-start trips per day and a reduction of 1,108 hot-start trips per day.

**Step 1c** in the emission methodology involves determining cold-start and hot-start emission factors. These changes are calculated *for a given pollutant and vehicle class* using the following formulas:

$$CST = (EXH_{100\%CST,26MPH} - EXH_{100\%STB,26MPH}) * 3.59$$
$$HST = (EXH_{100\%HST,26MPH} - EXH_{100\%STB,26MPH}) * 3.59$$

- In the formulas, CST is the cold-start emission factor in grams per trip, HST is the hot-start emission factor in grams per trip, and EXH is the MOBILE emission factor in grams per mile. The 3.59 factor is the FTP driving cycle trip-start miles per trip, and 26 miles per hour is the speed for the start portion of the FTP driving cycle. (<u>Note</u>: The subscripts on EXH refer to the operating conditions and speed at which MOBILE evaluates EXH. For example, "100%CST,26MPH" indicates 100% cold-start operating mode at 26 miles per hour vehicle speed. While "100%STB,26MPH" indicates 100% hot- or cold-stabilized operating mode at 26 mph vehicle speed.)

Using national default data from MOBILE, $CST_{LDGV,HC} = (2.55 - 0.95) * 3.59 = 5.74$ grams per trip, $CST_{LDGT1,HC} = (3.59 - 1.34) * 3.59 = 8.08$ grams per trip, $HST_{LDGV,HC} = (1.35 - 0.95) * 3.59 = 1.44$ grams per trip, and $HST_{LDGT1,HC} = (1.99 - 1.34) * 3.59 = 2.33$ grams per trip. (Following the same methodology, the cold-start and hot-start emission factors can also be determined for NOx and CO.)

**Step 1d** in the emission methodology involves determining cold-start and hot-start emission changes for the HOP service. These changes are calculated using the following formulas:

$$\Delta HC_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,HC}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,HC})$$
$$\Delta HC_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,HC}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,HC})$$

$$\Delta NOx_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,NOx}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,NOx})$$
$$\Delta NOx_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,NOx}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,NOx})$$

$$\Delta CO_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,CO}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,CO})$$
$$\Delta CO_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,CO}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,CO})$$

- In the formulas, $\Delta HC_{CST}$, $\Delta NOx_{CST}$, and $\Delta CO_{CST}$ are the changes in cold-start emissions for HC, NOx, and CO, respectively; and $\Delta HC_{HST}$, $\Delta NOx_{HST}$, and $\Delta CO_{HST}$ are the changes in hot-start emissions for HC, NOx, and CO, respectively. The other parameters in the formulas are defined in earlier steps of the methodology.

Using national default data from MOBILE, $\Delta HC_{CST} = (-1{,}200 * 0.785 * 5.74) + (-1{,}200 * 0.215 * 8.08) = -7{,}492$ and $\Delta HC_{HST} = (-1{,}108 * 0.785 * 1.44) + (-1{,}108 * 0.215 * 2.33) = -1{,}808$. Summarizing these results, the HOP service results in a reduction in cold-start HC emissions of 7,492 grams per day and a reduction in hot-start HC emissions of 1,808 grams per day. (Following the same methodology, the cold-start and hot-start emission changes can also be determined for NOx and CO.)

**Step 1e** in the emission methodology involves determining hot soak emission changes for the HOP service. These changes are calculated using the following formula:

$$\Delta HC_{HSK} = (\Delta TRIPS_{TOTAL} * \gamma_{TRIP,LDGV} * HSK_{LDGV}) + (\Delta TRIPS_{TOTAL} * \gamma_{TRIP,LDGT1} * HSK_{LDGT1})$$

- In the formula, $\Delta HC_{HSK}$ is the change in hot soak emissions, $\Delta TRIPS_{TOTAL}$ is the total change in trips, and HSK is the hot soak emission factor in grams per trip. (<u>Note</u>: Hot soak emissions are HC emissions only.)

$$\Delta TRIPS_{TOTAL} = \Delta NETRP_{W,P} + \Delta NETRP_{W,OP} + \Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP}.$$
Thus, $\Delta TRIPS_{TOTAL} = -218 + -146 + -583 + -1{,}360 = -2{,}307$.

Using national default data from MOBILE, $\Delta HC_{HSK} = (-2{,}307 * 0.785 * 3.06) + (-2{,}307 * 0.215 * 3.60) = -7{,}327$. Summarizing this result, the HOP service results in a reduction in hot soak emissions of 7,327 grams per day.

**Step 1f** in the emission methodology involves determining diurnal emission changes for the HOP service. These changes are calculated *for a given vehicle class* using the following formulas:

$$\Delta HC_{DNL,W} = 0.676 * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) / TPD_W * \gamma_{TRIP} * (WDI - MDI)$$
$$\Delta HC_{DNL,NW} = 0.676 * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP}) / TPD_{NW} * \gamma_{TRIP} * (WDI - MDI)$$
$$\Delta HC_{DNL} = \Delta HC_{DNL,W,LDGV} + \Delta HC_{DNL,NW,LDGV} + \Delta HC_{DNL,W,LDGT1} + \Delta HC_{DNL,NW,LDGT1}$$

- In the formulas, $\Delta HC_{DNL,W}$ is the change in diurnal emissions associated with work trips, $\Delta HC_{DNL,NW}$ is the change in diurnal emissions associated with non-work trips, and $\Delta HC_{DNL}$ is the total change in diurnal emissions. $TPD_W$ is the number of work trips per day per vehicle, and $TPD_{NW}$ is the number of non-work trips per day per vehicle. WDI is the weighted diurnal emission factor in grams, and MDI is the multi-day diurnal emission factor in grams. The other parameters in the formulas are defined in earlier steps of the methodology. (<u>Note</u>: Diurnal emissions are HC emissions only.)

The value used for $TPD_W$ is 2, since a commuter typically makes two work trips per day (i.e., one trip from home to work, one trip from work to home). $TPD_{NW}$ is equal to $TG_N$ from Step 3 of the "Travel Activity Effects" section above, and thus equals 2.

Using national default data from MOBILE, $\Delta HC_{DNL,W,LDGV} = 0.676 * (-218 + -146) / 2 * 0.785 * (3.30 - 6.04) = 265$, $\Delta HC_{DNL,NW,LDGV} = 0.676 * (-583 + -1{,}360) / 2 * 0.785 * (3.30 - 6.04) = 1{,}413$, $\Delta HC_{DNL,W,LDGT1} = 0.676 * (-218 + -146) / 2 * 0.215 * (5.11 - 15.33) = 270$, $\Delta HC_{DNL,NW,LDGT1} = 0.676 * (-583 + -1{,}360) / 2 * 0.215 * (5.11 - 15.33) = 1{,}443$, and $\Delta HC_{DNL} = 265 + 1{,}413 + 270 + 1{,}443 = 3{,}391$. Summarizing these results, the HOP service results in an increase in diurnal emissions of 3,391 grams per day.

**Step 1g** in the emission methodology involves calculating the total trip-related emission changes for the HOP service. These changes are calculated using the following formulas:

$$\Delta HC_{TRIP} = \Delta HC_{CST} + \Delta HC_{HST} + \Delta HC_{HSK} + \Delta HC_{DNL}$$
$$\Delta NOx_{TRIP} = \Delta NOx_{CST} + \Delta NOx_{HST}$$
$$\Delta CO_{TRIP} = \Delta CO_{CST} + \Delta CO_{HST}$$

- In the formulas, $\Delta HC_{TRIP}$, $\Delta NOx_{TRIP}$, and $\Delta CO_{TRIP}$ are the total changes in HC, NOx, and CO emissions, respectively, due to trip changes.

Using the data above, $\Delta HC_{TRIP}$ = -7,492 + -1,808 + -7,327 + 3,390 = -13,237. Summarizing this result, the HOP service results in a net decrease in trip-related HC emissions of 13,237 grams per day. (Following the same methodology, total trip-related emission changes can also be determined for NOx and CO.)

Emission Effects -- STEP 2 (VMT Changes)

**Step 2** in the estimation of the emission effects for the HOP service involves calculating the effect of VMT changes on emissions. This step is broken down into four smaller steps (2a through 2d), which are outlined below.

**Step 2a** in the emission methodology involves estimating the distribution of VMT changes for the HOP service. These changes are calculated using the following formulas:

$$\gamma_{VMT,LDGV} = VMT_{LDGV} / (VMT_{LDGV} + VMT_{LDGT1})$$
$$\gamma_{VMT,LDGT1} = 1 - \gamma_{VMT,LDGV}$$

- In the formulas, $\gamma_{VMT,LDGV}$ is the fraction of *TCM-affected* VMT for light-duty gasoline vehicles (LDGVs), $\gamma_{TRIP,LDGT1}$ is the fraction of *TCM-affected* VMT for light-duty gasoline trucks (LDGT1s), $VMT_{LDGV}$ is the fraction of *total* VMT in the region for LDGVs, and $VMT_{LDGT1}$ is the fraction of *total* VMT in the region for LDGT1s. (Note: Most TCMs that can be analyzed using EPA's guidance document affect only LDGVs or LDGT1s. Thus, the sum of $\gamma_{VMT,LDGV}$ and $\gamma_{VMT,LDGT1}$ is typically equal to one.)

$VMT_{LDGV}$ and $VMT_{LDGT1}$ are assumed to equal 0.626 and 0.171, respectively. These values are the national average default values used in MOBILE for VMT mix.

Using the data above, $\gamma_{VMT,LDGV}$ = 0.626 / (0.626 + 0.171) = 0.785 and $\gamma_{VMT,LDGT1}$ = 1 - 0.785 = 0.215. Summarizing these results, 78.5% of the VMT affected by the HOP service is by LDGVs, and 21.5% is by LDGT1s.

**Step 2b** in the emission methodology involves estimating hot-stabilized exhaust emission changes for the HOP service. These changes are calculated using the following formulas:

$$\Delta HC_{STB,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * STB_{LDGV,HC,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * STB_{LDGT1,HC,P})$$
$$\Delta HC_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,HC,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,HC,OP})$$

$$\Delta NOx_{STB,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * STB_{LDGV,NOx,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * STB_{LDGT1,NOx,P})$$

$$\Delta NOx_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,NOx,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,NOx,OP})$$

$$\Delta CO_{STB,P} = (\Delta NETVMT_{P} * \gamma_{VMT,LDGV} * STB_{LDGV,CO,P}) + (\Delta NETVMT_{P} * \gamma_{VMT,LDGT1} * STB_{LDGT1,CO,P})$$
$$\Delta CO_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,CO,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,CO,OP})$$

- In the formulas, $\Delta HC_{STB,P}$, $\Delta NOx_{STB,P}$, and $\Delta CO_{STB,P}$ are the peak-period changes in hot-stabilized emissions for HC, NOx, and CO, respectively; and $\Delta HC_{STB,OP}$, $\Delta NOx_{STB,OP}$, and $\Delta CO_{STB,OP}$ are the off-peak changes in hot-stabilized emissions for HC, NOx, and CO, respectively. $STB_P$ is the hot-stabilized emission factor (in grams per mile) for each pollutant and vehicle class for the peak period (during which average vehicle speed is assumed to be 20 miles per hour), and $STB_{OP}$ is the hot-stabilized emission factor (in grams per mile) for each pollutant and vehicle class for the off-peak period (during which average vehicle speed is assumed to be 35 miles per hour). The other parameters in the formulas are defined in earlier steps of the methodology.

Using national default data from MOBILE, $\Delta HC_{STB,P} = (-1{,}602 * 0.785 * 1.23) + (-1{,}602 * 0.215 * 1.77) = -2{,}156$ and $\Delta HC_{STB,OP} = (-3{,}012 * 0.785 * 0.69) + (-3{,}012 * 0.215 * 0.94) = -2{,}240$. Summarizing these results, the HOP service results in a reduction in peak-period hot-stabilized HC exhaust emissions of 2,156 grams per day and a reduction in off-peak hot-stabilized HC exhaust emissions of 2,240 grams per day. (Following the same methodology, hot-stabilized exhaust emission changes can also be determined for NOx and CO.)

**Step 2c** in the emission methodology involves estimating VMT-related evaporative emission changes for the HOP service. These changes are calculated using the following formulas:

$$\Delta HC_{VEVP,P} = (\Delta NETVMT_{P} * \gamma_{VMT,LDGV} * VEVP_{LDGV,P}) + (\Delta NETVMT_{P} * \gamma_{VMT,LDGT1} * VEVP_{LDGT1,P})$$
$$\Delta HC_{VEVP,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * VEVP_{LDGV,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * VEVP_{LDGT1,OP})$$

- In the formulas, $\Delta HC_{VEVP,P}$ is the change in peak-period evaporative emissions, $\Delta HC_{VEVP,OP}$ is the change in off-peak evaporative emissions, and VEVP is the VMT-related evaporative emission factor (in grams per mile) for each vehicle class and time period (peak or off-peak). The other parameters in the formulas are defined in earlier steps of the methodology. (<u>Note</u>: Evaporative emissions are HC emissions only.)

Using national default data from MOBILE, $\Delta HC_{VEVP,P} = (-1{,}602 * 0.785 * 0.44) + (-1{,}602 * 0.215 * 0.53) = -736$ and $\Delta HC_{VEVP,OP} = (-3{,}012 * 0.785 * 0.34) + (-3{,}012 * 0.215 * 0.44) = -1{,}089$. Summarizing these results, the HOP service results in a reduction in peak-period evaporative emissions of -736 grams per day and a reduction in off-peak evaporative emissions of 1,089 grams per day.

**Step 2d** in the emission methodology involves calculating the total VMT-related emission changes for the HOP service. These changes are calculated using the following formulas:

$$\Delta HC_{VMT} = \Delta HC_{STB,P} + \Delta HC_{STB,OP} + \Delta HC_{VEVP,P} + \Delta HC_{VEVP,OP}$$
$$\Delta NOx_{VMT} = \Delta NOx_{STB,P} + \Delta NOx_{STB,OP}$$
$$\Delta CO_{VMT} = \Delta CO_{STB,P} + \Delta CO_{STB,OP}$$

- In the formulas, $\Delta HC_{VMT}$, $\Delta NOx_{VMT}$, and $\Delta CO_{VMT}$ are the total changes in HC, NOx, and CO emissions, respectively, due to VMT changes.

Using the data above, $\Delta HC_{VMT}$ = -2,156 + -2,240 + -736 + -1,089 = -6,221. Summarizing this result, the HOP service results in a net decrease in VMT-related HC emissions of 6,221 grams per day. (Following the same methodology, total VMT-related emission changes can also be determined for NOx and CO.)

Emission Effects -- STEP 3 (Speed Changes)

**Step 3** in the estimation of the emission effects for the HOP service involves calculating the effect of speed changes on emissions. This step is broken down into four smaller steps (3a through 3d), which are outlined below.

**Step 3a** in the emission methodology involves estimating the speeds associated with the HOP service. These speeds are calculated using the following formulas:

$$SPEED_{P,TCM} = SPEED_{P,BASE} * (1 + \Delta SPD_P)$$
$$SPEED_{OP,TCM} = SPEED_{OP,BASE} * (1 + \Delta SPD_{OP})$$

- In the formulas, $SPEED_{P,TCM}$ is the peak-period speed after implementation of the TCM, $SPEED_{OP,TCM}$ is the off-peak speed after implementation of the TCM, $SPEED_{P,BASE}$ is the peak-period speed prior to implementation of the TCM, and $SPEED_{OP,BASE}$ is the off-peak speed prior to implementation of the TCM. The other parameters in the formulas are defined in earlier steps of the methodology.

Based on data for the national default fleet, $SPEED_{P,BASE}$ is assumed to be 20 miles per hour, and $SPEED_{OP,BASE}$ is assumed to be 35 miles per hour.

Using the data above, $SPEED_{P,TCM} = 20 * (1 + 0.004) = 20.08$ and $SPEED_{OP,TCM} = 35 * (1 + 0)$ = 35. Summarizing these results, peak-period speeds have slightly increased from 20 miles per hour to 20.08 miles per hour due to the HOP service. Off-peak speeds have not changed due to the service.

**Step 3b** in the emission methodology involves estimating the total VMT for the program area after implementation of the HOP service. These VMT figures are calculated using the following formulas:

$$VMT_{P,TCM} = TOTVMT_P + \Delta NETVMT_P$$
$$VMT_{OP,TCM} = TOTVMT_{OP} + \Delta NETVMT_{OP}$$

- In the formulas, $VMT_{P,TCM}$ is the total peak-period VMT in the program area after implementation of the TCM, and $VMT_{OP,TCM}$ is the total off-peak VMT in the program area after implementation of the TCM. The other parameters in the formulas are defined in earlier steps of the methodology.

Using data from Step 9 of the "Travel Activity Effects" section above, $VMT_{P,TCM} = 1,000,000$ + -1,602 = 998,398 and $VMT_{OP,TCM} = 1,000,000$ + -3,012 = 996,988. Summarizing these results, peak-period VMT has decreased from 1,000,000 miles per day to 998,398 miles per day due to the HOP service. Off-peak VMT has decreased from 1,000,000 miles per day to 996,988 miles per day due to the service.

**Step 3c** in the emission methodology involves estimating peak-period and off-peak emission changes due to changes in vehicle speeds. These changes are calculated using the following formulas:

$$\Delta HC_{SPD,P} = VMT_{P,TCM} * (STB_{FLT,HC,P,TCM} + RNL_{FLT,P,TCM}) - VMT_{P,TCM} * (STB_{FLT,HC,P,BASE} + RNL_{FLT,P,BASE})$$
$$\Delta HC_{SPD,OP} = VMT_{OP,TCM} * (STB_{FLT,HC,OP,TCM} + RNL_{FLT,OP,TCM}) - VMT_{OP,TCM} * (STB_{FLT,HC,OP,BASE} + RNL_{FLT,OP,BASE})$$

$$\Delta NOx_{SPD,P} = VMT_{P,TCM} * (STB_{FLT,NOx,P,TCM} - STB_{FLT,NOx,P,BASE})$$
$$\Delta NOx_{SPD,OP} = VMT_{OP,TCM} * (STB_{FLT,NOx,OP,TCM} - STB_{FLT,NOx,OP,BASE})$$

$$\Delta CO_{SPD,P} = VMT_{P,TCM} * (STB_{FLT,CO,P,TCM} - STB_{FLT,CO,P,BASE})$$
$$\Delta CO_{SPD,OP} = VMT_{OP,TCM} * (STB_{FLT,CO,OP,TCM} - STB_{FLT,CO,OP,BASE})$$

- In the formulas, $\Delta HC_{SPD,P}$, $\Delta NOx_{SPD,P}$, and $\Delta CO_{SPD,P}$ are the peak-period changes in emissions for HC, NOx, and CO, respectively, due to a change in speeds; and $\Delta HC_{SPD,OP}$, $\Delta NOx_{SPD,OP}$, and $\Delta CO_{SPD,OP}$ are the off-peak changes in emissions for HC, NOx, and CO, respectively, due to a change in speeds. $STB_{FLT}$ is the fleet-wide hot-stabilized emission factor (in grams per mile) for each pollutant, time period (i.e., peak or off-peak), and scenario (i.e., base or TCM). $RNL_{FLT}$ is the fleet-wide running loss emission factor (in grams per mile) for each time period and scenario. The other parameters in the formulas are defined in earlier steps of the methodology.

Based on data showing the relationship between vehicle speed and emissions, this analysis assumes that the elasticity of $STB_{FLT}$ with respect to speed is -1 for HC, 0 for NOx, and -1 for CO. Thus, a 1% increase in speed is assumed to result in a 1% decrease in HC and CO emissions (on a grams per mile basis) and no change in NOx emissions. The elasticity of $RNL_{FLT}$ with respect to speed is also assumed to be -1.

Using national default data from MOBILE, $\Delta HC_{SPD,P} = 998,398 * (1.669 + 0.211) - 998,398 * (1.676 + 0.212) = -0$ and $\Delta HC_{SPD,OP} = 996,988 * (1.938 + 0.120) - 996,988 * (1.938 + 0.120) = 0$. Summarizing these results, the HOP service changes neither speed-related HC emissions per day for the peak period nor speed-related HC emissions for the off-peak period. (Following the same methodology, the peak-period and off-peak emission changes due to changes in speeds can also be determined for NOx and CO.)

**Step 3d** in the emission methodology involves calculating the total speed-related emission changes for the HOP service. These changes are calculated using the following formulas:

$$\Delta HC_{SPD} = \Delta HC_{SPD,P} + \Delta HC_{SPD,OP}$$
$$\Delta NOx_{SPD} = \Delta NOx_{SPD,P} + \Delta NOx_{SPD,OP}$$
$$\Delta CO_{SPD} = \Delta CO_{SPD,P} + \Delta CO_{SPD,OP}$$

- In the formulas, $\Delta HC_{SPD}$, $\Delta NOx_{SPD}$, and $\Delta CO_{SPD}$ are the total changes in HC, NOx, and CO emissions, respectively, due to speed changes.

Using the data above, $\Delta HC_{SPD} = 0 + 0 = 0$. Summarizing this result, the HOP service results in no net change in speed-related HC emissions per day. (Following the same methodology, total speed-related emission changes can also be determined for NOx and CO.)

Emission Effects -- STEP 4 (Total)

**Step 4** in the estimation of the emission effects for the HOP service involves calculating the total changes in HC, NOx, and CO emissions. These changes are calculated using the following formulas:

$$\Delta HC = \Delta HC_{TRIP} + \Delta HC_{VMT} + \Delta HC_{SPD}$$
$$\Delta NOx = \Delta NOx_{TRIP} + \Delta NOx_{VMT} + \Delta NOx_{SPD}$$
$$\Delta CO = \Delta CO_{TRIP} + \Delta CO_{VMT} + \Delta CO_{SPD}$$

- In the formulas, $\Delta HC$, $\Delta NOx$, and $\Delta CO$ are the total changes in HC, NOx, and CO emissions, respectively, due to the TCM program.

Using the data above, $\Delta HC = -13,236 + -6,221 + 0 = -19,457$. Summarizing this result, the HOP service results in a net decrease in HC emissions of 19,457 grams per day, or approximately 0.019 tons per day. (Following the same methodology, total emission changes can also be determined for NOx and CO.)

# 2. ANALYSIS OF TCM PACKAGES

This section uses the methodology outlined in Chapters 2, 3, and 4 of EPA's TCM guidance to estimate the travel activity effects and emissions effects of programs involving TCM packages. The key distinction between the analysis presented in this section and the analysis in Section 1 is the need to first consider *modal choice*.

People tend to base their travel mode decisions on the attributes of each travel mode. The time it takes to get to a destination by a certain mode, the cost of a mode, the convenience of a particular mode, and mode reliability are the four characteristics people primarily consider when deciding on travel methods. EPA's methodology for TCM packages uses these attribute characteristics in a particular study area to determine the probability that a representative person in the affected community will choose a particular mode. These probabilities for a representative individual are then extrapolated to the whole study area population. When the characteristics of travel modes suddenly change (i.e. after TCM implementation), travel attributes change, and therefore mode choice probabilities for the representative individual and the entire study area also change. The TCM modeler can now compare the "pre-TCM" mode splits with the "post-TCM" splits to determine mode choice change due to the introduction of the TCM package.

Two analyses need to be conducted under the TCM package methodology before travel activity and emission changes can be determined. The first involves establishing the travel attribute characteristics and travel mode profiles that existed before introduction of the TCM package (i.e., a "base case"). The second analysis predicts travel choices after TCM implementation by plugging the new travel conditions into the base case framework. In other words, by multiplying the new travel attributes by preferences established in the base case, a new travel mode profile can be obtained.

## Example 6:    Cornell University Transportation Demand Management Program

General Description

The Cornell University Transportation Demand Management Program (TDMP) was instituted by the University in the early 1990s to combat significant traffic congestion near and on the Ithaca campus. Realizing that a parking pricing scheme alone would not be sufficient to alter faculty and staff work travel habits, the University's Office of Transportation Services (OTS) developed a transportation management package that, along with parking fees, included subsidized transit and rideshare measures.

The TDMP introduced several measures to encourage transit and carpooling. First, all but one campus parking lot began to charge single occupancy vehicles (SOVs). Second, a program called RideShare was established with a number of features, some key ones are a rideshare parking fee schedule that includes rebates in particular instances, a listing of people looking for others with whom to rideshare to help match people interested in carpooling, and emergency ride services to staff members who become stranded on campus due to missing their carpool rides. Finally, a program called OmniRide was developed. This program provides Cornell employees who do not participate in the RideShare program with free transit passes that can be used for work as well as leisure.

The Cornell TDMP has been quite successful, not only at reducing vehicle emissions as shown in the analysis below, but at saving large amounts of money for the university by enabling it to forgo large expenses for additional parking facilities that would have been needed otherwise. The university estimates that, without TDMP, construction of additional parking structures offering a total of 3,100

parking spaces would have been needed since 1991, when the program started. With TDMP the university has added a total of 350 parking spaces in that time period. Total cost savings to date from the forgone construction are estimated at $13 million.

A key factor in the success of the program has been the measures taken to provide backups, when needed, for commuters participating in the RideShare and OmniRide programs. Guaranteed rides home are available when program participants need them due to unforeseen circumstances. Participants also each receive a book of ten 1-day parking permits enabling them to drive alone on the occassional days when circumstances require them to have their cars at work. In special circumstances, such as the need to provide care to a family member for an extended period of time, participants may obtain additional books of permits.

Program officials also point to their outreach efforts as a key to their success. One tangible result is that they have gotten agreements from churches, town halls, grocery stores, and other facilites with parking lots that are not heavily used during weekday working hours, to allow RideShare participants to use their lots as park-and-ride lots.

Data Sources

- "Commuting Solutions Summary of Transportation Demand Management Program (TDMP)," Office of Transportation Services, June 1996.

- Cornell Commuter Report, Spring 1996.

- "Patterns and Trends: New York State Energy Profiles, 1981-1995," prepared by the New York State Energy Research and Development Authority.

- Personal Interview with David Lieb, Communications Manager, Office of Transportation and Mail Services, March 12, 1997, March 13, 1997, and March 17, 1997.

- Personal Interview with Lois Chaplin, University Bike Safety Specialist, March 12, 1997.

- Personal Interview with Nate Earlbomb, New York Department of Transportation, December 5, 1997.

- "Report on Reducing Oregon's Greenhouse Gas Emissions," prepared by the Oregon Office of Energy.

- "TCAT Service and Fare Consolidation Project: Tompkins Consolidated Area Transit, Ithaca, New York."

- Texas Transportation Institute web page.

- 1990 U.S. Census data.

- *1996 Statistical Abstract of the United States*.

Phase 1: Modal Choice Analysis

**Phase 1: Mode Choice Analysis**

Step 1: Base case (before TCM implementation) cost, time, convenience and reliability for each mode

Step 2: Highest and lowest possible values for time and cost among all modes

Step 3: Scale base-case cost, time, convenience, and reliability values for each mode on a "best-to-worst" scale

Step 4: Weight factors for cost, time, convenience and reliability

Step 5: Base case utilities for each travel mode (scale values times weight factors)

Step 6: Percentage of time in the base case a person will travel by each mode

Step 7: Percentage of time after TCM implementation a person will travel by each mode. This involves redoing steps 1 through 6 with values reflecting the TCM.

**Step 1** of the modal choice analysis for the TDMP involves determining the base case (i.e., prior to implementation of the TCM package) cost, time, convenience, and reliability for each mode of travel.

*Cost*

Relevant costs include parking fees, tolls, gasoline, and transit fees, although not every travel mode incurs all four costs. (For example, SOV travelers do not incur transit fees. Transit users, however, could face all four costs if they drive via a toll road to a transit station that charges for park-and-ride services.) Data needed to determine travel mode costs in the study area include the average distance to work for each mode, the fuel economy of passenger vehicles, gasoline prices, toll prices, parking prices, and transit prices.

Data on the average round-trip work travel distance for each travel mode in Tompkins County were not available from any consulted data sources. However, by cross-referencing the average trip

length and time for all American workers (obtained from the *1996 Statistical Abstract of the United States*) with average work trip time information for Tompkins County (obtained from 1990 U.S. Census data), the average one-way trip length in Tompkins County is determined to be 8.83 miles. Because the majority of trips to the Cornell campus before TCM implementation were made by SOVs (75%), this one-way trip length is assigned to the SOV mode. This analysis also assumes that carpool vehicles would need to travel an extra 2 miles on a one-way work trip to pick up passengers. Average transit distances and walk/bile distances in this particular case are relatively small.

Fuel economy for the Tompkins County area was derived using data from an Oregon Greenhouse Gas study, which reported that the average fuel economy for a passenger vehicle in 1991 (the year of TDMP implementation) was 20.1 miles per gallon (mpg). SOV fuel economy is increased to 20.3 mpg to account for the fact that most SOVs are passenger cars. Also, fuel economy for carpool vehicles

**FOCUS: COMPONENTS OF TRAVEL COST BY MODE**
Relevant costs for each travel mode are listed in the boxes below. While an SOV and a carpool vehicle encounter similar costs, total carpool costs need to be divided by average carpool vehicle occupancy (CVO) in order to determine cost per carpooler. (Note: This analysis is conducted from the perspective of an individual making a commuting decision, and thus costs need to be calculated on an individual basis.) Transit costs must include the costs incurred by the fraction of commuters who drive or get a ride to a transit stop. Finally, this analysis assumes that the walk/bike travel mode poses no cost to a commuter.

| SOV | Carpool | Transit |
|---|---|---|
| Fuel Prices | Fuel Prices | Transit Fees |
| Fuel Efficiency | Fuel Efficiency | |
| Parking Fees | Parking Fees | |
| Tolls | Tolls | |
| | *Note: Total cost needs to be divided by CVO to obtain cost faced by each individual.* | *Note: Mode cost must incorporate the costs to transit riders who drive to a transit stop, including fuel prices, fuel efficiency, parking fees, and tolls.* |

is lowered to 19.9 to account for the greater use of larger vehicles (e.g., mini-vans) and slower speeds.

Due to the lack of parking fees on the Cornell campus prior to TCM implementation and the non-existence of toll roads in Tompkins County, costs for SOV and carpool use are simply the price of gasoline consumed. (According to the NYSERDA, the average gasoline price in New York in 1991 was $1.33 per gallon.) This analysis assumes that the cost of gasoline is distributed evenly among all carpool

passengers (including the driver). Therefore, the cost of gasoline consumed for an individual in a carpool is determined by dividing the cost of gasoline by the average number of passengers in a carpool (2.18 in Tompkins County, as reported in 1990 U.S. Census data).

Based on the data above, the cost of SOV travel is calculated as follows: 17.67 miles (round trip) * $1.33 per gallon / 20.3 mpg = $1.16. The cost of carpool travel is calculated as follows: 22 miles (round trip) * $1.33 per gallon / 19.9 mpg / 2.18 = $0.67.

Total transit costs are the sum of two components. The first component, the price of using transit, is assumed to be $0.50, based on fee information found on the TCAT web site. The second component accounts for transit users who drive to a transit stop. Assuming that 30% of transit users drive to their stop, the average one-way distance to the park-and-ride stop is 1.5 miles, and average vehicle occupancy reflects county averages (1.21 according to 1990 U.S. Census data), the average one-way transit cost is calculated as follows: $0.50 + 0.3 * (1.5 miles * $1.33 per gallon / 20.1 mpg / 1.21) = $0.525. Multiplying this figure by 2 yields a round-trip cost of $1.05.

*Time*

For SOVs and carpools, round trip travel time is determined by dividing round trip travel distance by average speed. Speed data for SOVs and carpools is based on the national average for travel on principle arterial streets during peak hours. (Note: This analysis assumes most work trips take place during peak periods.) Because Tompkins County is largely rural and is not located near any major highway infrastructure, this analysis assumes that most travel is done on arterial roads. Carpool vehicles travel at slightly lower speeds due to the slow speeds involved when traveling in residential areas to pick up passengers. For walkers and bikers, the analysis assumes that the average speed is 5 miles per hour.

**FOCUS: COMPONENTS OF TRAVEL TIME BY MODE**
The factors that determine travel time for each mode are listed in the boxes below. SOV travel time is calculated by dividing travel distance by average vehicle speed. Carpool travel time is calculated in the same manner. However, it is important to note that carpool vehicles generally go slower and travel longer distances than SOVs due to passenger pick-up stops. In the TDMP base case, carpool vehicles are assumed to travel four miles more than SOVs and travel at a speed 3 miles per hour slower than SOVs. In addition to travel distance and vehicle speed, transit commute time is augmented by time spent waiting for transportation and time spent reaching the transit stop. Walk/bike commute time is calculated in the same manner as the SOV and carpool modes.

| Travel Distance | Travel Distance | Travel Distance | Travel Distance |
|---|---|---|---|
| Vehicle Speed | Vehicle Speed | Vehicle Speed | Mode Speed |
| | *Note: Travel distance will be affected by the number of carpool participants, and vehicle speed will be less than SOV speed due to multiple stops for passenger pickup.* | Time Spent Waiting at Transit Stop  Time Spent Traveling to and from Transit Stop | |
| ***SOV*** | ***Carpool*** | ***Transit*** | ***Walk/Bike*** |

To calculate travel time for transit, this analysis assumes that the average speed of a transit vehicle is 20 miles per hour. With a round trip of 13 miles, travel time is calculated to be 0.65 hours. EPA's TCM guidance suggests that walking and waiting time for transit amounts to approximately 8.76 minutes. This is multiplied by 2 to generate round-trip walking and waiting time for transit. Finally, there is additional driving time for the fraction of individuals who drive to park-and-ride lots. This is calculated by dividing the average round-trip distance for park-and-ride users by vehicle speed (assumed to be 30 miles per hour) and multiplying by the fraction of transit riders who use park-and-ride lots (0.3).

Based on the information above, the travel time for SOVs is 17.67 miles (round trip) / 30 miles per hour = 0.59 hours. The travel time for carpools is 22 miles (round trip) / 27 miles per hour = 0.81 hours. The travel time for transit is 13 miles (round trip) / 20 miles per hour + ((8.76 / 60) * 2) + (0.3 * (3 miles / 30 miles per hour)) = 0.97 hours. The travel time for walkers/bikers is 4.5 miles (round trip) / 5 miles per hour = 0.90 hours.

The costs and travel times associated with SOV travel, carpool travel, transit, and walking/biking for the base case are summarized below in Table 1.

**Table 1: Average Travel Cost and Time for the Base Case**

| Travel Mode | Total Daily Work Trip Length | Average Peak Period Speed | Hours of Daily Work Travel Time | Fuel Economy | Dollars per Gallon | Parking Fee | Transit Cost (one way) | Total Cost |
|---|---|---|---|---|---|---|---|---|
| Walk/Bike | 4.5 | 5 | 0.9 | N/A | N/A | N/A | N/A | - |
| Transit | 13 | 20 | 0.97 | 20.1 | $1.33 | N/A | $0.52 | $1.05 |
| Carpool | 22 | 27 | 0.81 | 19.9 | $1.33 | N/A | N/A | $0.67 |
| SOV | 17.67 | 30 | 0.59 | 20.3 | $1.33 | N/A | N/A | $1.16 |

<u>Note</u>: This methodology does not include the costs of wear-and-tear on privately-owned vehicles and thus may undervalue the true costs faced by SOV and carpool users. Nevertheless, wear-and-tear is an indirect cost that vehicle owners rarely account for in their work travel choices.
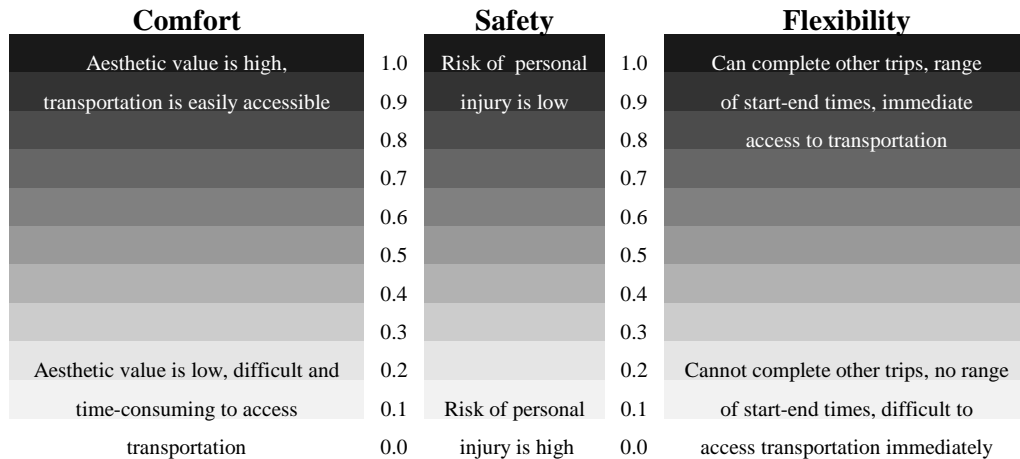
*Convenience*

Determining the convenience value for each travel mode primarily involves a qualitative analysis. Due to a lack of information on Tompkins County and the area around Cornell's campus, the convenience factors used on this analysis are based on factors shown in the TCM guidance for the San Francisco area, with a few minor adjustments. (<u>Note</u>: A convenience value of 0 indicates that an option is totally inconvenient, and a convenience value of 1 indicates that an option is totally convenient.)

- The convenience of SOV travel in Tompkins County is given a value 0.9. While the guidance gives SOVs a value of 0.8, the lack of a transit system in Tompkins County similar to BART and the relative spread of development in Tompkins County when compared to the density of San Francisco would seem to encourage SOV use in Tompkins County to a greater extent.

- The convenience of transit in Tompkins County is given a value of 0.2. The TCM guidance gives transit a value of 0.4 for San Francisco. However, the Bay Area's extensive transit system is much more comprehensive than the system serving Tompkins County.

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- The convenience of carpool travel in Tompkins County is given a value of 0.2. While ridesharing in San Francisco is given a convenience value of 0.3, the lack of congestion and spread of development in Tompkins County makes ridesharing less convenient than it is in San Francisco.

- The convenience of walking/biking in Tompkins County is given a value of 0.1. While walking and biking can be very convenient for some people, for many it is not a viable option.

**FOCUS: ASSESSING CONVENIENCE OF EACH MODE**

The convenience of a particular mode is largely determined by three factors -- comfort, safety, and flexibility. If a mode provides physical comfort, is relatively non-stressful, and does not prevent commuters from indulging in their favorite travel habits, such as listening to the radio or drinking coffee, its convenience value will be fairly high. Convenience value will also be enhanced by feelings of safety. (For example, many observers partially attribute the recent popularity of sport utility vehicles to the feeling of safety these vehicles provide.) If a transportation choice allows the commuter to complete errands before and after work and provides flexibility in departure time, convenience value for that particular mode will be relatively high. Conversely, a transportation choice that makes commuting taxing and stressful, provides little transportation flexibility, and is prone more than any other mode to cause physical injury will be relatively inconvenient and an unpopular modal choice.

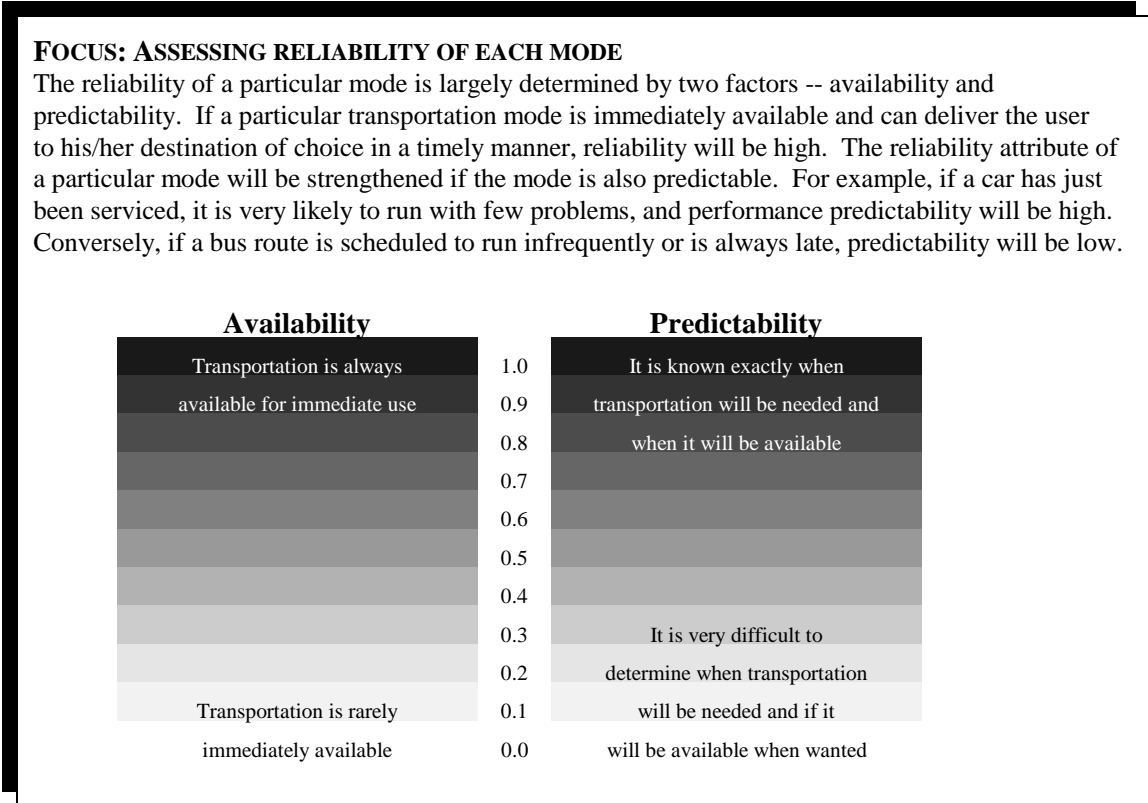| Comfort | | Safety | | Flexibility | |
|---|---|---|---|---|---|
| Aesthetic value is high, | 1.0 | Risk of personal | 1.0 | Can complete other trips, range | |
| transportation is easily accessible | 0.9 | injury is low | 0.9 | of start-end times, immediate | |
| | 0.8 | | 0.8 | access to transportation | |
| | 0.7 | | 0.7 | | |
| | 0.6 | | 0.6 | | |
| | 0.5 | | 0.5 | | |
| | 0.4 | | 0.4 | | |
| | 0.3 | | 0.3 | | |
| Aesthetic value is low, difficult and | 0.2 | | 0.2 | Cannot complete other trips, no range | |
| time-consuming to access | 0.1 | Risk of personal | 0.1 | of start-end times, difficult to | |
| transportation | 0.0 | injury is high | 0.0 | access transportation immediately | |

*Reliability*

Like convenience value, reliability can only be determined by a qualitative assessment. (Note: A reliability value of 0 indicates that an option is totally unreliable, and a reliability value of 1 indicates that an option is totally reliable.)

- The reliability of SOV travel is given a value of 0.9. This is based on the fact that (1) the vehicle is immediately available, (2) travel does not depend on anyone else, and (3) there is a slight chance that a vehicle will experience mechanical failure.

- The reliability of walking/biking is given a value of 0.4.  This is based on that fact that (1) travel does not depend on anyone else, (2) immobility is generally not a problem, and (3) inclement weather can make this option intolerable.

- The reliability of carpool travel is given a value of 0.2. This is based on that fact that ridesharers depend on the cooperation of others.

- The reliability of transit is given a value of 0.2. This is based on that fact that (1) transit riders often experience delays, and (2) transit systems sometimes experience mechanical failures.

**FOCUS: ASSESSING RELIABILITY OF EACH MODE**
The reliability of a particular mode is largely determined by two factors -- availability and predictability.  If a particular transportation mode is immediately available and can deliver the user to his/her destination of choice in a timely manner, reliability will be high.  The reliability attribute of a particular mode will be strengthened if the mode is also predictable.  For example, if a car has just been serviced, it is very likely to run with few problems, and performance predictability will be high.  Conversely, if a bus route is scheduled to run infrequently or is always late, predictability will be low.

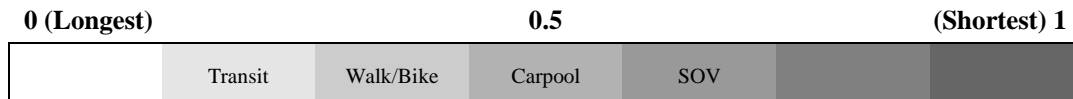| Availability | | Predictability |
|---|---|---|
| Transportation is always | 1.0 | It is known exactly when |
| available for immediate use | 0.9 | transportation will be needed and |
|  | 0.8 | when it will be available |
|  | 0.7 |  |
|  | 0.6 |  |
|  | 0.5 |  |
|  | 0.4 |  |
|  | 0.3 | It is very difficult to |
|  | 0.2 | determine when transportation |
| Transportation is rarely | 0.1 | will be needed and if it |
| immediately available | 0.0 | will be available when wanted |

**Step 2** of the modal choice analysis for the TDMP involves determining the best and worst limits of the cost and travel time profiles for the base case.

The best cost is the lowest cost among the four modes.  Based on an example shown in the TCM guidance document, the worst cost limit is derived by multiplying the highest cost among the four modes by a factor of approximately 1.8.  Therefore, the best cost is $0, and the worst cost is $2.08 (i.e., 1.8 * $1.16).

The best travel time involves no travel at all.  For example, a faculty member who lives in a dormitory experiences virtually no travel time.  On the other hand, for people who commute over long distances, travel time can easily extend over an hour.  Therefore, the best travel time is assumed to be 0, and the worst travel time is assumed to be 1.5 hours.

**Step 3** of the modal choice analysis for the TDMP involves scaling the base case cost, time, convenience, and reliability of each travel mode on a "best-to-worst" scale. To scale the cost and time of each mode on a best-to-worst scale (1 representing the best value and 0 the worst value), the following formulas are used:
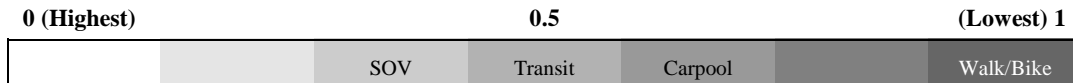
$$\text{COSTVAL}_k = (\text{worst cost} - \text{COST}_k) / (\text{worst cost} - \text{best cost})$$
$$\text{TIMEVAL}_k = (\text{worst time} - \text{TIME}_k) / (\text{worst time} - \text{best time})$$

- In the formulas, $\text{COSTVAL}_k$ is the cost value for travel mode k, $\text{TIMEVAL}_k$ is the time value of travel mode k, $\text{COST}_k$ is the cost of mode k, and $\text{TIME}_k$ is the travel time of mode k.

Based on the analysis above, $\text{COSTVAL}_{\text{Walk/Bike}} = (2.08 - 0) / (2.08 - 0) = 1$, $\text{COSTVAL}_{\text{Transit}}$

$= (2.08 - 1.05) / (2.08 - 0) = 0.497$, $COSTVAL_{Carpool} = (2.08 - 0.67) / (2.08 - 0) = 0.676$, and $COSTVAL_{SOV} = (2.08 - 1.16) / (2.08 - 0) = 0.444$. Also, $TIMEVAL_{Walk/Bike} = (1.5 - 0.9) / (1.5 - 0) = 0.400$, $TIMEVAL_{Transit} = (1.5 - 0.97) / (1.5 - 0) = 0.352$, $TIMEVAL_{Carpool} = (1.5 - 0.81) / (1.5 - 0) = 0.457$, and $TIMEVAL_{SOV} = (1.5 - 0.59) / (1.5 - 0) = 0.607$. (Note: The values for convenience and reliability are assumed to be the same as those calculated in Step 1 above.)

**FOCUS: COMPARING RELIABILITY ACROSS MODES**

The availability and predictability of SOV use is very high, although congestion can serve to reduce the reliability of SOVs. SOV use is given a reliability factor of 0.9 in the TDMP base case. Transit scores very low on availability and predictability and is given an overall value of 0.2 in the base case. Carpools are similarly limited in the availability and predictability categories, resulting in an overall convenience score of 0.2 in the base case. Finally, walking/biking is a readily available and predictable mode during good weather. However, during inclement weather, the reliability, and predictability of this mode is low. In addition, since walking/biking is not a viable option for commuters who live several miles from their work sites, the overall reliability score of this mode must be adjusted downward. In the base case, walking/biking is assigned a reliability value of 0.4.

**Comfort**

| 0 (Worst) | | | 0.5 | | | (Best) 1 |
|---|---|---|---|---|---|---|
| | Transit | Carpool | Walk/Bike | | | SOV |
| Carpool | Transit | | Walk/ Bike* | | | SOV |

**Safety**

| 0 (Worst) | | | 0.5 | | | (Best) 1 |
|---|---|---|---|---|---|---|
| | | SOV | Carpool | Transit | Walk/ | (Best) 1 |
| | Transit | Carpool | Walk/ Bike* | | | SOV |

**Predictability**

**Flexibility**

| 0 (Worst) | | | 0.5 | | | (Best) 1 |
|---|---|---|---|---|---|---|
| | Transit | Carpool | | | Walk/ Bike* | SOV |

* These scores only apply to commuters who live close enough to their work sites to make this mode a viable option.

**Step 4** of the modal choice analysis for the TDMP involves determining a base case weight profile for the population of the program area. This step involves assigning the relative importance of each attribute from the perspective of the average member of the study population. The "weight profile" must sum to one (i.e., 100% of the travel decision process is affected by these four attributes). The TCM guidance suggests initial relative weights of 0.3 for cost, 0.3 for travel time, 0.2 for convenience, and 0.2 for reliability. Based on survey data for the TDMP and calculations performed under Steps 5 and 6 below, the relative weights ultimately used in this analysis for cost, time, convenience, and reliability are 0.3, 0.19, 0.3, and 0.21, respectively.

**FOCUS: SOME FACTORS MATTER MORE THAN OTHERS**

How much does the average member of the TCM program area value cost in comparison with convenience? What weight should be attached to reliability? The answers to these questions will help determine the relative importance of the four travel attributes for the region being studied. This relative importance is reflected in the "weight profile." For example, if cost is valued more than time in a particular community, any TCM that decreases cost will have a greater chance of affecting behavior than a TCM that modifies travel time. The TCM guidance suggests an initial weight profile. However, analysts will need to make appropriate judgements to determine the weight profile of the particular area being studied.

**Step 5** of the modal choice analysis for the TDMP involves calculating the total utilities of each mode of travel for the base case. These utilities are determined for each travel mode using the following formula:

$$TU_k = COSTVAL_k * \lambda_1 + CONVVAL_k * \lambda_2 + TIMVAL_k * \lambda_3 + RELVAL_k * \lambda_4$$

- In the formula, $TU_k$ is the total utility of travel mode k, $COSTVAL_k$ is the cost value of mode k, $CONVVAL_k$ is the convenience value of mode k, $TIMVAL_k$ is the time value of mode k, and $RELVAL_k$ is the reliability value of mode k. $\lambda_1$ is the relative weight on cost, $\lambda_2$ is the relative weight on convenience, $\lambda_3$ is the relative weight on time, and $\lambda_4$ is the relative weight on reliability.

Based on the analysis above, $TU_{Walk/Bike} = 1 * 0.3 + 0.1 * 0.3 + 0.4 * 0.19 + 0.4 * 0.21 = 0.49$, $TU_{Transit} = 0.497 * 0.3 + 0.2 * 0.3 + 0.352 * 0.19 + 0.2 * 0.21 = 0.32$, $TU_{Carpool} = 0.676 * 0.3 + 0.2 * 0.3 + 0.457 * 0.19 + 0.2 * 0.21 = 0.39$, and $TU_{SOV} = 0.444 * 0.3 + 0.9 * 0.3 + 0.607 * 0.19 + 0.9 * 0.21 = 0.71$.

**Step 6** of the modal choice analysis for the TDMP involves estimating the percentage of time (i.e., probability) that a person from the program area will travel via a given mode of travel in the base case. This percentage is calculated for each travel mode using the following formula:

$$P_k = e^{6.5TU}{}_k / \sum_{j=1}^{N} e^{6.5TU}{}_j$$

- In the formula, $P_k$ is the probability that a person from the program area will travel via mode k relative to the N modes examined.

Table 2 below presents the results of Step 6 for the base case. As can be seen from the table, the estimated probabilities correspond closely to actual mode splits.

**Table 2:  Travel Mode Choice for the Base Case**

| Mode Split | SOV | Carpool | Transit | Walk/Bike |
|---|---|---|---|---|
| Actual | 74.9 | 4.4 | 4.4 | 16.4 |
| Projected | 68.9 | 8.8 | 5.5 | 16.8 |

**Step 7** of the modal choice analysis for the TDMP involves estimating the percentage of time (i.e., probability) that a person from the program area will travel via a given mode of travel *after implementation of the TCM package*. This requires repeating Steps 1 through 6 above using data and assumptions applicable to the TCM package (see Steps 7a through 7f below).

**Step 7a** of the modal choice analysis for the TDMP involves determining the TCM-adjusted cost, time, convenience, and reliability for each mode of travel.

*Cost*

For SOVs, the weighted average price for parking due to the TCM is calculated to be $0.83. The parking fee for carpools is calculated to be $0.12 and includes both fees and rebates. Rebates are offered to cars with three or more people that park in specific lots. Based on 1990 U.S. Census data

for Tompkins County, this analysis assumes that 86.4% of carpools contain 2 people, 10.6% contain 3 people, and 3% have 4 or more people. The analysis also assumes that an even distribution of carpool vehicles use the four campus carpool lots. Both carpools and SOVs incur gasoline costs, which are added to the parking fees. Based on this information, the total costs for SOVs and carpools are estimated to be $1.99 and $0.79, respectively.

The only cost for transit is the gasoline used by park-and-ride participants. As in Step 1 above, this step assumes that 30% of the people who use transit drive to the transit station and that these vehicles on average contain 1.21 people. The cost of using transit is estimated to be $0.05 after implmentation of the TCM.

*Time*

The time attributes for each travel mode do not change due to the TCM package, given no significant change in average speeds. In addition, congestion would be reduced equally for every mode of travel (except for walking and biking).

The costs and travel times associated with SOV travel, carpool travel, transit, and walking/biking for the TCM case are summarized below in Table 3.

**Table 3:  Average Travel Cost and Time After Implementation of the TCM**

| Travel Mode | Total Daily Work Trip Length | Average Peak Period Speed | Hours of Daily Work Travel Time | Fuel Economy | Dollars per Gallon | Parking Fee | Transit Cost (one way) | Total Cost |
|---|---|---|---|---|---|---|---|---|
| Walk/Bike | 4.5 | 5 | 0.9 | N/A | N/A | N/A | N/A | - |
| Transit | 13 | 20 | 0.97 | 20.1 | $1.33 | N/A | $0.02 | $0.05 |
| Carpool | 22 | 27 | 0.81 | 19.9 | $1.33 | $0.12 | N/A | $0.79 |
| SOV | 17.67 | 30 | 0.59 | 20.3 | $1.33 | $0.83 | N/A | $1.99 |

Note: This methodology does not include the costs of wear-and-tear on privately-owned vehicles and thus may undervalue the true costs faced by SOV and carpool users.  Nevertheless, wear-and-tear is an indirect cost that vehicle owners rarely account for in their work travel choices.

*Convenience*

After implementation of the TCM, the convenience of SOV travel does not change, as nothing is done to make SOV use more or less convenient. Due to the improvements resulting from the TCM, however, the convenience of transit use is assumed to increase from 0.2 to 0.25. Similarly, the convenience of carpooling is assumed to increase from 0.2 to 0.35, and the convenience of walking/ biking is assumed to increase from 0.1 to 0.2.

*Reliability*

After implementation of the TCM, the reliability of SOV travel does not change, as nothing is done to make SOV use more or less reliable. Due to the improvements resulting from the TCM, however, the reliability of transit use is assumed to increase from 0.2 to 0.25. Similarly, the reliability of carpooling is assumed to increase from 0.2 to 0.3, and the reliability of walking/biking is assumed to increase from 0.4 to 0.45.

**Step 7b** of the modal choice analysis for the TDMP involves determining the best and worst limits of the cost and travel time profiles for the TCM case.

The best cost is the lowest cost among the four modes. Based on an example shown in the guidance document, the worst cost limit is derived by multiplying the highest cost among the four modes by a factor of approximately 1.8. Therefore, the best cost is $0, and the worst cost is $3.58 (i.e., 1.8 * $1.99).

The best and worst travel times for the TCM case are assumed to be the same as in the base case. Thus, the best travel time is 0, and the worst travel time is 1.5 hours.

**Step 7c** of the modal choice analysis for the TDMP involves scaling the TCM-adjusted cost, time, convenience, and reliability of each travel mode on a "best-to-worst" scale using the formulas shown in Step 3 above. Based on the analysis above, $COSTVAL_{Walk/Bike} = (3.58 - 0) / (3.58 - 0) = 1$, $COSTVAL_{Transit} = (3.58 - 0.05) / (3.58 - 0) = 0.986$, $COSTVAL_{Carpool} = (3.58 - 0.79) / (3.58 - 0) = 0.779$, and $COSTVAL_{SOV} = (3.58 - 1.99) / (3.58 - 0) = 0.444$. Also, $TIMEVAL_{Walk/Bike} = (1.5 - 0.9) / (1.5 - 0) = 0.400$, $TIMEVAL_{Transit} = (1.5 - 0.97) / (1.5 - 0) = 0.352$, $TIMEVAL_{Carpool} = (1.5 - 0.81) / (1.5 - 0) = 0.457$, and $TIMEVAL_{SOV} = (1.5 - 0.59) / (1.5 - 0) = 0.607$. (<u>Note</u>: The values for convenience and reliability are assumed to be the same as those calculated in Step 7a above.)

**Step 7d** of the modal choice analysis for the TDMP involves determining a weight profile for the population of the program area after implementation of the TCM. The TCM guidance calls for this profile to be the same as the profile determined in the base case. Thus, the relative weights for cost, time, convenience, and reliability are 0.3, 0.19, 0.3, and 0.21, respectively.

**Step 7e** of the modal choice analysis for the TDMP involves calculating the total utilities of each mode of travel for the TCM case. These utilities are determined for each travel mode using the formula shown in Step 5 above. Based on the analysis above, $TU_{Walk/Bike} = 1 * 0.3 + 0.2 * 0.3 + 0.4 * 0.19 + 0.45 * 0.21 = 0.53$, $TU_{Transit} = 0.986 * 0.3 + 0.3 * 0.3 + 0.352 * 0.19 + 0.25 * 0.21 = 0.51$, $TU_{Carpool} = 0.779 * 0.3 + 0.35 * 0.3 + 0.457 * 0.19 + 0.3 * 0.21 = 0.49$, and $TU_{SOV} = 0.444 * 0.3 + 0.9 * 0.3 + 0.607 * 0.19 + 0.9 * 0.21 = 0.71$.

**Step 7f** of the modal choice analysis for the TDMP involves estimating the percentage of time (i.e., probability) that a person from the program area will travel via a given mode of travel after implementation of the TCM. This percentage is calculated for each travel mode using the formula shown in Step 6 above. Table 4 below presents the mode splits estimated under the TCM case, along with the mode splits estimated for the base case.

**Table 4: Travel Mode Choice Before and After Implementation of the TCM**

| Mode Split | SOV | Carpool | Transit | Walk/Bike |
|---|---|---|---|---|
| Base Case | 68.9 | 8.8 | 5.5 | 16.8 |
| TCM Case | 54.8 | 13.2 | 14.7 | 17.3 |

**Step 8** of the modal choice analysis for the TDMP involves estimating the daily changes in the number of work trips made using each mode of travel. These changes are derived using the changes in the number of Cornell faculty and staff who use each mode, as shown in Table 5 below.

**Table 5:  Change in Number of People Using Each Mode Per Day (N = 11,481)**

|  | SOV | Carpool | Transit | Walk/Bike |
|---|---|---|---|---|
| Projected Before TCM Implementation | 7,916 | 1,015 | 628 | 1,923 |
| Projected After TCM Implementation | 6,293 | 1,512 | 1,688 | 1,989 |
| Change in Mode Choice (Number of People) | -1,623 | 497 | 1,060 | 66 |

The changes shown in Table 5 are converted into work trip changes as follows:

- For the SOV mode, 1,623 cars are now left at home.  This number is multiplied by 2 to reflect that work trips involve a return trip, thus yielding a total of 3,246 trips reduced per day.

- After TCM implementation, there are 497 additional carpoolers.  An example in the TCM guidance indicates that 33% of new carpoolers join existing carpools, 62% of new carpoolers form new carpools that do not drive to park-and-ride lots, and 5% of new carpoolers form new carpools that drive to park-and-ride lots.  Based on these percentages, the total trip increase by new carpools is estimated to be 285.

- Of the 1,060 new transit users, this analysis assumes that 30%, or 318, drive to park-and-ride lots.  This number is divided by average vehicle occupancy for Tompkins County, yielding an additional 263 vehicles (not including carpool park-and-ride vehicles) making trips to park-and-ride lots.  Multiplying this figure by 2 (to account for return trips) yields 526 additional trips.

As shown in Table 6 below, summing the change in trips for each category (SOV, carpool, and transit) yields a net reduction of 2,435 trips per day for the TDMP.

**Table 6:  Work Trip Changes Per Day**

| | | |
|---|---|---|
| Transit | 526 | |
| New Carpools | 282 | |
| New Carpools with Park-and-Ride | 3 | (equivalent carpool trips) |
| Drive Alone | -3,246 | |
| Total Trip Change | -2,435 | |

Phase 2: Travel Activity Effects

**Step 1** in the estimation of travel activity effects, which involves an assessment of the potential trip effects from the TCM program, is not applicable in this case.

**Step 2** in the travel activity methodology involves estimating the *direct* work and non-work trip reductions from the TDMP. Direct trip reductions are calculated using the following formulas:

$$\Delta TRIPS_{D,W} = \omega * \Delta TRIPS_D$$
$$\Delta TRIPS_{D,NW} = (1 - \omega) * \Delta TRIPS_D$$

- In the formulas, $\Delta TRIPS_D$ is the total direct trip reduction, $\Delta TRIPS_{D,W}$ is the direct work trip reduction, $\Delta TRIPS_{D,NW}$ is the direct non-work trip reduction, and $\omega$ is the fraction of trip effects that are work-related.

$\Delta TRIPS_D$ is calculated in Table 6 above to be -2,435 trips per day.

Due to the fact that TDMP is assumed to affect only work-related trips, the parameter $\omega$ is set equal to 1.

Using the data above, $\Delta TRIPS_{D,W} = 1 * -2,435 = -2,435$, and $\Delta TRIPS_{D,NW} = (1 - 1) * -2,435 = 0$. Summarizing these results, the TDMP is responsible for directly reducing 2,435 trips per day, all of which are work-related.

**Step 3** in the travel activity methodology involves estimating the actual *indirect* trip increases (for both work and non-work trips) from the TDMP. Indirect trip increases are secondary effects that typically result when vehicles normally used for commuting are left at home. These increases are calculated using the following formulas:

$$\Delta TRIPS_{I,W} = INC_{W,H} * -\Delta TRIPS_D / 2$$
$$\Delta TRIPS_{I,NW} = INC_{N,H} * -\Delta TRIPS_D / 2$$

- In the formulas, $\Delta TRIPS_{I,W}$ is the indirect work trip increase, $\Delta TRIPS_{I,NW}$ is the indirect non-work trip increase, and $INC_{W,H}$ and $INC_{N,H}$ are the rates of increased SOV work and non-work trip making by household members of TCM participants who leave their vehicles at home. The other parameter in the formulas is defined in an earlier step of the methodology.

$INC_{W,H}$ is defined as $NV * SHR * (SIZE - 1) * EMP * TG_W$, where NV is the fraction of the population that does not own a vehicle (Note: This analysis interprets this parameter to mean the percentage of drivers without a vehicle, which is estimated as the percentage of vehicle-owning households in the program area that have only one vehicle.), SHR is the fraction of shared mode trips, SIZE is average household size, EMP is the fraction of the population that is employed, and $TG_W$ is the work trip generation rate for SOV users. NV is assumed to be 44%, based on U.S. Census data for Tompkins County. The TDMP data indicate that 13.2% of work trips are in carpools and 14.7% are on buses, resulting in an SHR estimate of 27.9%. (Note: This variable uses estimates generated after TCM

introduction.)  SIZE is assumed to be 2.46, based on 1990 U.S. Census data.  The value for EMP is 59% and is taken from 1990 U.S. Census data.  Based on an example in the TCM guidance, $TG_W$ is assumed to equal 1.71.  Based on these numbers, $INC_{W,H} = 0.44 * 0.279 * (2.46 - 1) * 0.59 * 1.71 = 0.18$.

$INC_{N,H}$ is defined as $NV * SHR * (SIZE - 1) * UNEMP * TG_N$, where NV, SHR, and SIZE are as defined above, UNEMP is the fraction of the population that is not employed, and $TG_N$ is the non-work trip generation rate for SOV users.  UNEMP is simply (1 - EMP) and thus equals 41%.  $TG_N$ is assumed to be the same as $TG_W$ (i.e., 1.71).  Based on these numbers, $INC_{N,H} = 0.44 * 0.279 * (2.46 - 1) * 0.41 * 1.71 = 0.13$.

Using the data above, $\Delta TRIPS_{I,W} = 0.18 * -(2,435) / 2 = 219$, and $\Delta TRIPS_{I,NW} = 0.13 * -(2,435) / 2 = 158$.  Summarizing these results, the TDMP is indirectly responsible for an increase of 219 work trips per day and 158 non-work trips per day.

**Step 4** in EPA's methodology for estimating travel activity effects of TCMs, which involves determining direct peak and off-peak period trip shifts, is not relevant to the analysis of the TDMP.

**Step 5** in the travel activity methodology involves estimating the net trip changes from the TDMP as distributed between work and non-work trips and peak and off-peak periods.  These changes are calculated using the following formulas:

$$\Delta NETRP_{W,P} = \omega * \Delta TRIPS_{S,P} + PK_W * (\Delta TRIPS_{D,W} + \Delta TRIPS_{I,W})$$
$$\Delta NETRP_{W,OP} = \omega * \Delta TRIPS_{S,OP} + (1 - PK_W) * (\Delta TRIPS_{D,W} + \Delta TRIPS_{I,W})$$
$$\Delta NETRP_{NW,P} = (1 - \omega) * \Delta TRIPS_{S,P} + PK_{NW} * (\Delta TRIPS_{D,NW} + \Delta TRIPS_{I,NW})$$
$$\Delta NETRP_{NW,OP} = (1 - \omega) * \Delta TRIPS_{S,OP} + (1 - PK_{NW}) * (\Delta TRIPS_{D,NW} + \Delta TRIPS_{I,NW})$$

- In the formulas, $\Delta NETRP_{W,P}$ is the net work trip change in the peak period, $\Delta NETRP_{W,OP}$ is net work trip change in the off-peak period, $\Delta NETRP_{NW,P}$ is the net non-work trip change in the peak period, and $\Delta NETRP_{NW,OP}$ is the net non-work trip change in the off-peak period.  $\Delta TRIPS_{S,P}$ is the change in peak period trips, and $\Delta TRIPS_{S,OP}$ is the change in off-peak period trips.  $PK_W$ is the observed fraction of work trips during the peak period, and $PK_{NW}$ is the observed fraction of non-work trips during the peak period.  The other parameters in the formulas are defined in earlier steps of the methodology.

Because there are no trip shifts associated with the TDMP (see Step 4), $\Delta TRIPS_{S,P}$ and $\Delta TRIPS_{S,OP}$ are each equal to 0.

The values used for $PK_W$ and $PK_{NW}$ are 0.7 and 0.3, respectively, based on an example in the TCM guidance and assuming that peak travel hours are from 6 a.m. to 9 a.m. and 4 p.m. to 7 p.m.

Using the data above, $\Delta NETRP_{W,P} = 0 + 0.7 * (-2,435 + 219) = -1,551$, $\Delta NETRP_{W,OP} = 0 + (1 - 0.7) * (-2,435 + 219) = -665$, $\Delta NETRP_{NW,P} = 0 + 0.3 * (0 + 158) = 47$, and $\Delta NETRP_{NW,OP} = 0 * (1 - 0.3) * (0 + 158) = 107$.  Summarizing these results, the TDMP results in net decreases in peak and off-peak work trips of 1,551 per day and 665 per day, respectively.  The program also results in increases in peak and off-peak non-work trips of 47 per day and 107 per day, respectively.

**Step 6** in the travel activity methodology involves estimating the peak and off-peak VMT changes due to the trip changes from the TDMP.  These changes are calculated using the following formulas:

$$\Delta VMT_P = (\Delta NETRP_{W,P} * DIST_W) + (\Delta NETRP_{NW,P} * DIST_{NW})$$
$$\Delta VMT_{OP} = (\Delta NETRP_{W,OP} * DIST_W) + (\Delta NETRP_{NW,OP} * DIST_{NW})$$

- In the formulas, $\Delta VMT_P$ is the change in peak-period VMT due to trip changes, $\Delta VMT_{OP}$ is the change in off-peak VMT due to trip changes, $DIST_W$ is the average VMT per trip for work trips, and $DIST_{NW}$ is the average VMT per trip for non-work trips. The other parameters in the formulas are defined in earlier steps of the methodology.

$DIST_W$ is derived to be 8.51 miles per trip based on the analysis of modal choice. $DIST_{NW}$ is assumed to be 6.3 miles, based on work trip data for Tompkins County and data on work and non-work trip distances reported in the *1996 Statistical Abstract of the United States*.

Using the data above, $\Delta VMT_P = (-1,551 * 8.51) + (47 * 6.3) = -12,903$ and $\Delta VMT_{OP} = (-665 * 8.51) + (107 * 6.3) = -4,978$. Summarizing these results, the TDMP reduces peak-period VMT by 12,903 miles per day due to trip changes and reduces off-peak VMT by 4,978 miles per day due to trip changes.

**Step 7** in the travel activity methodology involves estimating the VMT changes due to trip length changes resulting from the TDMP. This step is not necessary, as it has been accounted for in the estimation of $\Delta TRIPS_D$.

**Step 8** in the travel activity methodology involves estimating the total peak and off-peak VMT changes resulting from the TDMP. These changes are calculated using the following formulas:

$$\Delta NETVMT_P = \Delta VMT_P + PK_W * \Delta VMT_{L,W} + PK_{NW} * \Delta VMT_{L,NW}$$
$$\Delta NETVMT_{OP} = \Delta VMT_{OP} + (1 - PK_W) * \Delta VMT_{L,W} + (1 - PK_{NW}) * \Delta VMT_{L,NW}$$

- In the formulas, $\Delta NETVMT_P$ is the total change in peak period VMT, and $\Delta NETVMT_{OP}$ is the total change in off-peak VMT. The other parameters in the formulas are defined in earlier steps of the methodology.

Because VMT changes due to trip length changes have already been accounted for in the analysis, $\Delta VMT_{L,W}$ and $\Delta VMT_{L,NW}$ are each set equal to 0.

Using the data above, $\Delta NETVMT_P = -12,903 + 0.7 * 0 + 0.3 * 0 = -12,903$ and $\Delta NETVMT_{OP} = -4,978 + (1 - 0.7) * 0 + (1 - 0.3) * 0 = -4,978$. Summarizing these results, the TDMP reduces peak-period VMT by a total of 12,903 miles per day and off-peak VMT by a total of 4,978 miles per day.

**Step 9** in the travel activity methodology involves estimating peak and off-peak speed changes resulting from the TDMP. These changes are calculated using the following formulas:

$$\Delta SPD_P = (\Delta NETVMT_P / TOTVMT_P) * \epsilon_P$$
$$\Delta SPD_{OP} = (\Delta NETVMT_{OP} / TOTVMT_{OP}) * \epsilon_{OP}$$

- In the formulas, $\Delta SPD_P$ is the percentage change in peak-period speeds, $\Delta SPD_{OP}$ is the change in off-peak speeds, $TOTVMT_P$ is total peak-period VMT for the program area, $TOTVMT_{OP}$ is total off-peak VMT for the program area, $\epsilon_P$ is the elasticity of peak-period speed with respect to volume, and $\epsilon_{OP}$ is the elasticity of off-peak speed with respect to volume. The other parameters in the formulas are defined in earlier steps of the methodology.

Total VMT in Tompkins County is approximately 1,662,000 miles per day. This analysis assumes that half of this VMT is work-related. Combining this information with the assumptions from Step 5 that 70% of work-related trips occur in the peak period and 30% of non-work trips occur in the peak period yields a value of 831,000 miles per day for each of $TOTVMT_P$ and $TOTVMT_{OP}$.

The parameter $\epsilon_P$ is assumed to be -0.75, based on an example provided in the TCM guidance document. The parameter $\epsilon_{OP}$ is assumed to be 0, because changes in off-peak VMT are not likely to affect vehicle speeds (i.e., due to a lack of congestion).

Using the data above, $\Delta SPD_P = -12{,}903$ / $831{,}000 * -0.75 = 0.0116$ and $\Delta SPD_{OP} = -4{,}978$ / $831{,}000 * 0 = 0$. Summarizing these results, the TDMP increases peak-period speeds by approximately 1.16% but has no effect on off-peak speeds.

Phase 3: Emission Effects -- STEP 1 (Trip Changes)

**Step 1** in the estimation of the emission effects for the TDMP involves calculating the effect of trip changes on emissions. This step is broken down into seven smaller steps (1a through 1g), which are outlined below.

**Step 1a** in the emission methodology involves estimating the distribution of trip changes for the TDMP. These changes are calculated using the following formulas:

$$\gamma_{TRIP,LDGV} = TRIP_{LDGV} / (TRIP_{LDGV} + TRIP_{LDGT1})$$
$$\gamma_{TRIP,LDGT1} = 1 - \gamma_{TRIP,LDGV}$$

**Phase 3: Effects on Emissions**
- Step 1: Effect of trip changes on emissions
  - 1a: Distribution of trip changes among vehicle types
  - 1b: Changes in cold-start and hot-start trips
  - 1c: Cold-start and hot-start emission factors by pollutant and vehicle type
  - 1d: Cold-start and hot-start emission changes for the project
  - 1e: Hot-soak emission changes
  - 1f: Diurnal changes by vehicle type
  - 1g: Summation of trip related emission changes
- Step 2: Effect of VMT changes on emissions
  - 2a: Distribution of VMT changes among vehicle types
  - 2b: Hot-stabilized exhaust emission changes by vehicle type
  - 2c: VMT-related evaporative emission changes
  - 2d: Summation of VMT-related emission changes
- Step 3: Emission effects due to speed changes
  - 3a: Peak and off-peak speed after implementation
  - 3b: Peak and off-peak VMT after implementation
  - 3c: Peak and off-peak emissions changes due to changes in speeds
  - 3d: Summation of speed related changes
- Step 4: Summation of emission effects

- In the formulas, $\gamma_{TRIP,LDGV}$ is the fraction of *TCM-affected* trips taken by light-duty gasoline vehicles (LDGVs), $\gamma_{TRIP,LDGT1}$ is the fraction of *TCM-affected* trips taken by light-duty gasoline trucks (LDGT1s), $TRIP_{LDGV}$ is the fraction of *total* trips in the region taken by LDGVs, and $TRIP_{LDGT1}$ is the fraction of *total* trips in the region taken by LDGT1s. (Note: Most TCMs that can be analyzed using EPA's guidance document affect only LDGVs or LDGT1s. Thus, the sum of $\gamma_{TRIP,LDGV}$ and $\gamma_{TRIP,LDGT1}$ is typically equal to one.)

According to a study on the TDMP, $TRIP_{LDGV}$ and $TRIP_{LDGT1}$ *for the program area* are equal to 0.86 and 0.14, respectively.

Using the data above, $\gamma_{TRIP,LDGV} = 0.86 / (0.86 + 0.14) = 0.86$ and $\gamma_{TRIP,LDGT1} = 1 - 0.86 = 0.14$. Summarizing these results, 86% of the trips affected by the TDMP are taken by LDGVs, and 14% are taken by LDGT1s.

**Step 1b** in the emission methodology involves calculating cold-start and hot-start trip changes for the TDMP. These changes are calculated using the following formulas:

$$\Delta TRIPS_{CST} = \gamma_{CST,W} * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) + \gamma_{CST, NW} * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP})$$
$$\Delta TRIPS_{HST} = (1 - \gamma_{CST,W}) * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) + (1 - \gamma_{CST,NW}) * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP})$$

- In the formulas, $\Delta TRIPS_{CST}$ is the number of cold-start trip changes, $\Delta TRIPS_{HST}$ is the number of hot-start trip changes, $\gamma_{CST,W}$ is the fraction of work trips begun in the cold-start mode, and $\gamma_{CST, NW}$ is the fraction of non-work trips begun in the cold-start mode. The other parameters in the formulas are defined in earlier steps of the methodology.

Because work trips are mostly cold-start trips, the guidance calls for $\gamma_{CST,W}$ to be set equal to 1. The guidance also suggests that $\gamma_{CST,NW}$ be set equal to 0.43, which is the default fraction of cold starts used in the Federal Test Procedure (FTP).

Using the data above, $\Delta TRIPS_{CST} = 1 * (-1,551 + -665) + 0.43 * (47 + 107) = -2,150$ and $\Delta TRIPS_{HST} = (1 - 1) * (-1,551 + -665) + (1 - 0.43) * (47 + 107) = 88$. Summarizing these results, the TDMP results in a reduction of 2,150 cold-start trips per day and an increase of 88 hot-start trips per day.

**Step 1c** in the emission methodology involves determining cold-start and hot-start emission factors. These changes are calculated *for a given pollutant and vehicle class* using the following formulas:

$$CST = (EXH_{100\%CST,26MPH} - EXH_{100\%STB,26MPH}) * 3.59$$
$$HST = (EXH_{100\%HST,26MPH} - EXH_{100\%STB,26MPH}) * 3.59$$

- In the formulas, CST is the cold-start emission factor in grams per trip, HST is the hot-start emission factor in grams per trip, and EXH is the MOBILE emission factor in grams per mile. The 3.59 factor is the FTP driving cycle trip-start miles per trip, and 26 miles per hour is the speed for the start portion of the FTP driving cycle. (Note: The subscripts on EXH refer to the operating conditions and speed at which MOBILE evaluates EXH. For example, "100%CST,26MPH" indicates 100% cold-start operating mode at 26 miles per hour vehicle speed.)

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Using national default data from MOBILE, $CST_{LDGV,HC} = (2.55 - 0.95) * 3.59 = 5.74$ grams per trip, $CST_{LDGT1,HC} = (3.59 - 1.34) * 3.59 = 8.08$ grams per trip, $HST_{LDGV,HC} = (1.35 - 0.95) * 3.59 = 1.44$ grams per trip, and $HST_{LDGT1,HC} = (1.99 - 1.34) * 3.59 = 2.33$ grams per trip. (Following the same methodology, the cold-start and hot-start emission factors can also be determined for NOx and CO.)

**Step 1d** in the emission methodology involves determining cold-start and hot-start emission changes for the TDMP. These changes are calculated using the following formulas:

$$\Delta HC_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,HC}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,HC})$$
$$\Delta HC_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,HC}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,HC})$$

$$\Delta NOx_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,NOx}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,NOx})$$
$$\Delta NOx_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,NOx}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,NOx})$$

$$\Delta CO_{CST} = (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGV} * CST_{LDGV,CO}) + (\Delta TRIPS_{CST} * \gamma_{TRIP,LDGT1} * CST_{LDGT1,CO})$$
$$\Delta CO_{HST} = (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGV,CO}) + (\Delta TRIPS_{HST} * \gamma_{TRIP,LDGT1} * HST_{LDGT1,CO})$$

- In the formulas, $\Delta HC_{CST}$, $\Delta NOx_{CST}$, and $\Delta CO_{CST}$ are the changes in cold-start emissions for HC, NOx, and CO, respectively; and $\Delta HC_{HST}$, $\Delta NOx_{HST}$, and $\Delta CO_{HST}$ are the changes in hot-start emissions for HC, NOx, and CO, respectively. The other parameters in the formulas are defined in earlier steps of the methodology.

Using national default data from MOBILE, $\Delta HC_{CST} = (-2,150 * 0.86 * 5.74) + (-2,150 * 0.14 * 8.08) = -13,045$ and $\Delta HC_{HST} = (88 * 0.86 * 1.44) + (88 * 0.14 * 2.33) = 138$. Summarizing these results, the TDMP results in a reduction in cold-start HC emissions of 13,045 grams per day and an increase in hot-start HC emissions of 138 grams per day. (Following the same methodology, the cold-start and hot-start emission changes can also be determined for NOx and CO.)

**Step 1e** in the emission methodology involves determining hot soak emission changes for the TDMP. These changes are calculated using the following formula:

$$\Delta HC_{HSK} = (\Delta TRIPS_{TOTAL} * \gamma_{TRIP,LDGV} * HSK_{LDGV}) + (\Delta TRIPS_{TOTAL} * \gamma_{TRIP,LDGT1} * HSK_{LDGT1})$$

- In the formula, $\Delta HC_{HSK}$ is the change in hot soak emissions, $\Delta TRIPS_{TOTAL}$ is the total change in trips, and HSK is the hot soak emission factor in grams per trip. (<u>Note</u>: Hot soak emissions are HC emissions only.)

$\Delta TRIPS_{TOTAL} = \Delta NETRP_{W,P} + \Delta NETRP_{W,OP} + \Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP}$. Thus, $\Delta TRIPS_{TOTAL} = -1,551 + -665 + 47 + 107 = -2,062$.

Using national default data from MOBILE, $\Delta HC_{HSK} = (-2,062 * 0.86 * 3.06) + (-2,062 * 0.14 * 3.60) = -6,466$. Summarizing this result, the TDMP results in a reduction in hot soak emissions of 6,466 grams per day.

**Step 1f** in the emission methodology involves determining diurnal emission changes for the TDMP. These changes are calculated *for a given vehicle class* using the following formulas:

$$\Delta HC_{DNL,W} = 0.676 * (\Delta NETRP_{W,P} + \Delta NETRP_{W,OP}) / TPD_W * \gamma_{TRIP} * (WDI - MDI)$$
$$\Delta HC_{DNL,NW} = 0.676 * (\Delta NETRP_{NW,P} + \Delta NETRP_{NW,OP}) / TPD_{NW} * \gamma_{TRIP} * (WDI - MDI)$$

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$$\Delta HC_{DNL} = \Delta HC_{DNL,W,LDGV} + \Delta HC_{DNL,NW,LDGV} + \Delta HC_{DNL,W,LDGT1} + \Delta HC_{DNL,NW,LDGT1}$$

- In the formulas, $\Delta HC_{DNL,W}$ is the change in diurnal emissions associated with work trips, $\Delta HC_{DNL,NW}$ is the change in diurnal emissions associated with non-work trips, and $\Delta HC_{DNL}$ is the total change in diurnal emissions. $TPD_W$ is the number of work trips per day per vehicle, and $TPD_{NW}$ is the number of non-work trips per day per vehicle. WDI is the weighted diurnal emission factor in grams, and MDI is the multi-day diurnal emission factor in grams. The other parameters in the formulas are defined in earlier steps of the methodology. (Note: Diurnal emissions are HC emissions only.)

The value used for $TPD_W$ is 2, since a commuter makes typically makes two work trips per day (i.e., one trip from home to work, one trip from work to home). $TPD_{NW}$ is equal to $TG_N$ from Step 3 of the "Travel Activity Effects" section above, and thus equals 1.71.

Using national default data from MOBILE, $\Delta HC_{DNL,W,LDGV} = 0.676 * (-1,551 + -665) / 2 * 0.86 * (3.30 - 6.04) = 1,765$, $\Delta HC_{DNL,NW,LDGV} = 0.676 * (47 + 107) / 1.71 * 0.86 * (3.30 - 6.04) = -143$, $\Delta HC_{DNL,W,LDGT1} = 0.676 * (-1,551 + -665) / 2 * 0.14 * (5.11 - 15.33) = 1,072$, $\Delta HC_{DNL,NW,LDGT1} = 0.676 * (47 + 107) / 1.71 * 0.14 * (5.11 - 15.33) = -87$, and $\Delta HC_{DNL} = 1,765 + -143 + 1,072 + -87 = 2607$. Summarizing these results, the TDMP results in a net increase in diurnal emissions of 2,607 grams per day.

**Step 1g** in the emission methodology involves calculating the total trip-related emission changes for the TDMP. These changes are calculated using the following formulas:

$$\Delta HC_{TRIP} = \Delta HC_{CST} + \Delta HC_{HST} + \Delta HC_{HSK} + \Delta HC_{DNL}$$
$$\Delta NOx_{TRIP} = \Delta NOx_{CST} + \Delta NOx_{HST}$$
$$\Delta CO_{TRIP} = \Delta CO_{CST} + \Delta CO_{HST}$$

- In the formulas, $\Delta HC_{TRIP}$, $\Delta NOx_{TRIP}$, and $\Delta CO_{TRIP}$ are the total changes in HC, NOx, and CO emissions, respectively, due to trip changes.

Using the data above, $\Delta HC_{TRIP} = -13,045 + 138 + -6,466 + 2,607 = -16,766$. Summarizing this result, the TDMP results in a net decrease in trip-related HC emissions of 16,766 grams per day. (Following the same methodology, total trip-related emission changes can also be determined for NOx and CO.)

Emission Effects -- STEP 2 (VMT Changes)

**Step 2** in the estimation of the emission effects for the TDMP involves calculating the effect of VMT changes on emissions. This step is broken down into four smaller steps (2a through 2d), which are outlined below.

**Step 2a** in the emission methodology involves estimating the distribution of VMT changes for the TDMP. These changes are calculated using the following formulas:

$$\gamma_{VMT,LDGV} = VMT_{LDGV} / (VMT_{LDGV} + VMT_{LDGT1})$$
$$\gamma_{VMT,LDGT1} = 1 - \gamma_{VMT,LDGV}$$

- In the formulas, $\gamma_{VMT,LDGV}$ is the fraction of *TCM-affected* VMT for light-duty gasoline vehicles (LDGVs), $\gamma_{TRIP,LDGT1}$ is the fraction of *TCM-affected* VMT

for light-duty gasoline trucks (LDGT1s), $VMT_{LDGV}$ is the fraction of *total* VMT in the region for LDGVs, and $VMT_{LDGT1}$ is the fraction of *total* VMT in the region for LDGT1s. (Note: Most TCMs that can be analyzed using EPA's guidance document affect only LDGVs or LDGT1s. Thus, the sum of $\gamma_{VMT,LDGV}$ and $\gamma_{VMT,LDGT1}$ is typically equal to one.)

According to a study on the TDMP, $VMT_{LDGV}$ and $VMT_{LDGT1}$ *for the program area* are equal to 0.86 and 0.14, respectively.

Using the data above, $\gamma_{VMT,LDGV} = 0.86 / (0.86 + 0.14) = 0.86$ and $\gamma_{VMT,LDGT1} = 1 - 0.86 = 0.14$. Summarizing these results, 86% of the VMT affected by the TDMP is by LDGVs, and 14% is by LDGT1s.

**Step 2b** in the emission methodology involves estimating hot-stabilized exhaust emission changes for the TDMP. These changes are calculated using the following formulas:

$$\Delta HC_{STB,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * STB_{LDGV,HC,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * STB_{LDGT1,HC,P})$$
$$\Delta HC_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,HC,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,HC,OP})$$

$$\Delta NOx_{STB,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * STB_{LDGV,NOx,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * STB_{LDGT1,NOx,P})$$
$$\Delta NOx_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,NOx,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,NOx,OP})$$

$$\Delta CO_{STB,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * STB_{LDGV,CO,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * STB_{LDGT1,CO,P})$$
$$\Delta CO_{STB,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * STB_{LDGV,CO,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * STB_{LDGT1,CO,OP})$$

- In the formulas, $\Delta HC_{STB,P}$, $\Delta NOx_{STB,P}$, and $\Delta CO_{STB,P}$ are the peak-period changes in hot-stabilized emissions for HC, NOx, and CO, respectively; and $\Delta HC_{STB,OP}$, $\Delta NOx_{STB,OP}$, and $\Delta CO_{STB,OP}$ are the off-peak changes in hot-stabilized emissions for HC, NOx, and CO, respectively. $STB_P$ is the hot-stabilized emission factor (in grams per mile) for each pollutant and vehicle class for the peak period (during which average vehicle speed is assumed to be 20 miles per hour), and $STB_{OP}$ is the hot-stabilized emission factor (in grams per mile) for each pollutant and vehicle class for the off-peak period (during which average vehicle speed is assumed to be 35 miles per hour). The other parameters in the formulas are defined in earlier steps of the methodology.

Using national default data from MOBILE, $\Delta HC_{STB,P} = (-12,903 * 0.86 * 1.23) + (-12,903 * 0.14 * 1.77) = -16,846$ and $\Delta HC_{STB,OP} = (-4,978 * 0.86 * 0.69) + (-4,978 * 0.14 * 0.94) = -3,609$. Summarizing these results, the TDMP results in a reduction in peak-period hot-stabilized HC exhaust emissions of 16,846 grams per day and a reduction in off-peak hot-stabilized HC exhaust emissions of 3,609 grams per day. (Following the same methodology, hot-stabilized exhaust emission changes can also be determined for NOx and CO.)

**Step 2c** in the emission methodology involves estimating VMT-related evaporative emission changes for the TDMP. These changes are calculated using the following formulas:

$$\Delta HC_{VEVP,P} = (\Delta NETVMT_P * \gamma_{VMT,LDGV} * VEVP_{LDGV,P}) + (\Delta NETVMT_P * \gamma_{VMT,LDGT1} * VEVP_{LDGT1,P})$$
$$\Delta HC_{VEVP,OP} = (\Delta NETVMT_{OP} * \gamma_{VMT,LDGV} * VEVP_{LDGV,OP}) + (\Delta NETVMT_{OP} * \gamma_{VMT,LDGT1} * VEVP_{LDGT1,OP})$$

- In the formulas, $\Delta HC_{VEVP,P}$ is the change in peak-period evaporative emissions, $\Delta HC_{VEVP,OP}$ is the change in off-peak evaporative emissions, and VEVP is the VMT-related evaporative emission factor (in grams per mile) for each vehicle class and time period (peak or off-peak). The other parameters in the formulas are defined in earlier steps of the methodology. (Note: Evaporative emissions are HC emissions only.)

Using national default data from MOBILE, $\Delta HC_{VEVP,P} = (-12,903 * 0.86 * 0.44) + (-12,903 * 0.14 * 0.53) = -5,840$ and $\Delta HC_{VEVP,OP} = (-4,978 * 0.86 * 0.34) + (-4,978 * 0.14 * 0.44) = -1,762$. Summarizing these results, the TDMP results in a reduction in peak-period evaporative emissions of 5,840 grams per day and a reduction in off-peak evaporative emissions of 1,762 grams per day.

**Step 2d** in the emission methodology involves calculating the total VMT-related emission changes for the TDMP. These changes are calculated using the following formulas:

$$\Delta HC_{VMT} = \Delta HC_{STB,P} + \Delta HC_{STB,OP} + \Delta HC_{VEVP,P} + \Delta HC_{VEVP,OP}$$
$$\Delta NOx_{VMT} = \Delta NOx_{STB,P} + \Delta NOx_{STB,OP}$$
$$\Delta CO_{VMT} = \Delta CO_{STB,P} + \Delta CO_{STB,OP}$$

- In the formulas, $\Delta HC_{VMT}$, $\Delta NOx_{VMT}$, and $\Delta CO_{VMT}$ are the total changes in HC, NOx, and CO emissions, respectively, due to VMT changes.

Using the data above, $\Delta HC_{VMT} = -16,846 + -3,609 + -5,840 + -1,762 = -28,057$. Summarizing this result, the TDMP results in a net decrease in VMT-related HC emissions of 28,057 grams per day. (Following the same methodology, total VMT-related emission changes can also be determined for NOx and CO.)

Emission Effects -- STEP 3 (Speed Changes)

**Step 3** in the estimation of the emission effects for the TDMP involves calculating the effect of speed changes on emissions. This step is broken down into four smaller steps (3a through 3d), which are outlined below.

**Step 3a** in the emission methodology involves estimating the speeds associated with the TDMP. These speeds are calculated using the following formulas:

$$SPEED_{P,TCM} = SPEED_{P,BASE} * (1 + \Delta SPD_P)$$
$$SPEED_{OP,TCM} = SPEED_{OP,BASE} * (1 + \Delta SPD_{OP})$$

- In the formulas, $SPEED_{P,TCM}$ is the peak-period speed after implementation of the TCM, $SPEED_{OP,TCM}$ is the off-peak speed after implementation of the TCM, $SPEED_{P,BASE}$ is the peak-period speed prior to implementation of the TCM, and $SPEED_{OP,BASE}$ is the off-peak speed prior to implementation of the TCM. The other parameters in the formulas are defined in earlier steps of the methodology.

For this analysis, $SPEED_{P,BASE}$ is assumed to be 30 miles per hour, and $SPEED_{OP,BASE}$ is assumed to be 35 miles per hour.

Using the data above, $SPEED_{P,TCM} = 30 * (1 + 0.0116) = 30.35$ and $SPEED_{OP,TCM} = 35 * (1 + 0) = 35$. Summarizing these results, peak-period speeds have slightly increased from 30 miles per hour

to 30.35 miles per hour due to the TDMP.  Off-peak speeds have not changed due to the program.

**Step 3b** in the emission methodology involves estimating the total VMT for the program area after implementation of the TDMP.  These VMT figures are calculated using the following formulas:

$$VMT_{P,TCM} = TOTVMT_P + \Delta NETVMT_P$$
$$VMT_{OP,TCM} = TOTVMT_{OP} + \Delta NETVMT_{OP}$$

- In the formulas, $VMT_{P,TCM}$ is the total peak-period VMT in the program area after implementation of the TCM, and $VMT_{OP,TCM}$ is the total off-peak VMT in the program area after implementation of the TCM.  The other parameters in the formulas are defined in earlier steps of the methodology.

Using data from Step 9 of the "Travel Activity Effects" section above, $VMT_{P,TCM} = 831,000 + -12,903 = 818,097$ and $VMT_{OP,TCM} = 831,000 + -4,978 = 826,022$.  Summarizing these results, peak-period VMT has decreased from 831,000 miles per day to 818,097 miles per day due to the TDMP.  Off-peak VMT has decreased from 831,000 miles per day to 826,022 miles per day due to the program.

**Step 3c** in the emission methodology involves estimating peak-period and off-peak emission changes due to changes in vehicle speeds.  These changes are calculated using the following formulas:

$$\Delta HC_{SPD,P} = VMT_{P,TCM} * (STB_{FLT,HC,P,TCM} + RNL_{FLT,P,TCM}) - VMT_{P,TCM} * (STB_{FLT,HC,P,BASE} + RNL_{FLT,P,BASE})$$
$$\Delta HC_{SPD,OP} = VMT_{OP,TCM} * (STB_{FLT,HC,OP,TCM} + RNL_{FLT,OP,TCM}) - VMT_{OP,TCM} * (STB_{FLT,HC,OP,BASE} + RNL_{FLT,OP,BASE})$$

$$\Delta NOx_{SPD,P} = VMT_{P,TCM} * (STB_{FLT,NOx,P,TCM} - STB_{FLT,NOx,P,BASE})$$
$$\Delta NOx_{SPD,OP} = VMT_{OP,TCM} * (STB_{FLT,NOx,OP,TCM} - STB_{FLT,NOx,OP,BASE})$$

$$\Delta CO_{SPD,P} = VMT_{P,TCM} * (STB_{FLT,CO,P,TCM} - STB_{FLT,CO,P,BASE})$$
$$\Delta CO_{SPD,OP} = VMT_{OP,TCM} * (STB_{FLT,CO,OP,TCM} - STB_{FLT,CO,OP,BASE})$$

- In the formulas, $\Delta HC_{SPD,P}$, $\Delta NOx_{SPD,P}$, and $\Delta CO_{SPD,P}$ are the peak-period changes in emissions for HC, NOx, and CO, respectively, due to a change in speeds; and $\Delta HC_{SPD,OP}$, $\Delta NOx_{SPD,OP}$, and $\Delta CO_{SPD,OP}$ are the off-peak changes in emissions for HC, NOx, and CO, respectively, due to a change in speeds.  $STB_{FLT}$ is the fleet-wide hot-stabilized emission factor (in grams per mile) for each pollutant, time period (i.e., peak or off-peak), and scenario (i.e., base or TCM).  $RNL_{FLT}$ is the fleet-wide running loss emission factor (in grams per mile) for each time period and scenario.  The other parameters in the formulas are defined in earlier steps of the methodology.

Based on data showing the relationship between vehicle speed and emissions, this analysis assumes that the elasticity of $STB_{FLT}$ with respect to speed is -1 for HC, 0 for NOx, and -1 for CO.  Thus, a 1% increase in speed is assumed to result in a 1% decrease in HC and CO emissions (on a grams per mile basis) and no change in NOx emissions.  The elasticity of $RNL_{FLT}$ with respect to speed is also assumed to be -1.

Using national default data from MOBILE, $\Delta HC_{SPD,P} = 818,097 * (1.916 + 0.119) - 818,097 * (1.938 + 0.120) = -18,816$ and $\Delta HC_{SPD,OP} = 826,022 * (1.938 + 0.120) - 826,022 * (1.938 + 0.120) = 0$.  Summarizing these results, the TDMP results in a decrease in speed-related HC emissions of 18,816 grams per day for the peak period but does not change speed-related HC emissions for the off-peak

period. (Following the same methodology, the peak-period and off-peak emission changes due to changes in speeds can also be determined for NOx and CO.)

**Step 3d** in the emission methodology involves calculating the total speed-related emission changes for the TDMP. These changes are calculated using the following formulas:

$$\Delta HC_{SPD} = \Delta HC_{SPD,P} + \Delta HC_{SPD,OP}$$
$$\Delta NOx_{SPD} = \Delta NOx_{SPD,P} + \Delta NOx_{SPD,OP}$$
$$\Delta CO_{SPD} = \Delta CO_{SPD,P} + \Delta CO_{SPD,OP}$$

- In the formulas, $\Delta HC_{SPD}$, $\Delta NOx_{SPD}$, and $\Delta CO_{SPD}$ are the total changes in HC, NOx, and CO emissions, respectively, due to speed changes.

Using the data above, $\Delta HC_{SPD} = -18,816 + 0 = -18,816$. Summarizing this result, the TDMP results in a net decrease in speed-related HC emissions of 18,816 grams per day. (Following the same methodology, total speed-related emission changes can also be determined for NOx and CO.)

Emission Effects -- STEP 4 (Total)

**Step 4** in the estimation of the emission effects for the TDMP involves calculating the total changes in HC, NOx, and CO emissions. These changes are calculated using the following formulas:

$$\Delta HC = \Delta HC_{TRIP} + \Delta HC_{VMT} + \Delta HC_{SPD}$$
$$\Delta NOx = \Delta NOx_{TRIP} + \Delta NOx_{VMT} + \Delta NOx_{SPD}$$
$$\Delta CO = \Delta CO_{TRIP} + \Delta CO_{VMT} + \Delta CO_{SPD}$$

- In the formulas, $\Delta HC$, $\Delta NOx$, and $\Delta CO$ are the total changes in HC, NOx, and CO emissions, respectively, due to the TCM program.

Using the data above, $\Delta HC = -16,766 + -28,057 + -18,816 = -63,639$. Summarizing this result, the TDMP results in a net decrease in HC emissions of 63,639 grams per day, or approximately 0.07 tons per day. (Following the same methodology, total emission changes can also be determined for NOx and CO.)