Transportation

Fossil-fuel powered vehicles are the primary source of GHG emissions within the transportation sector. On-road vehicles traditionally use gasoline and diesel fuel and release emissions based on the amount of fuel combusted and the emission factor of the engine. Cleaner-fueled and electric powered vehicles can also generate GHG emissions, but often at far lower intensities.

Transportation emissions can be reduced by improving the emissions profile of the vehicle fleet or by reducing VMT. Most of the transportation measures quantified in this Handbook aim to reduce VMT and encourage mode shifts from single-occupancy vehicles to shared (e.g., transit) or active modes of transportation (e.g., bicycle). This can be accomplished by coordinating trip reduction or incentive programs; optimizing the land use of the project study area; enhancing road, bike and pedestrian networks; implementing parking policies; or improving transit systems.

WHAT'S ELASTICITY?

Elasticity refers to how much one variable changes, relative to a change in another variable. For example, the elasticity of a VMT reduction measure would measure how much VMT is reduced in proportion to the increase in bicycle lanes.

Most of the emission reductions are determined by evaluating the *elasticity* of a measure relative to the amount of VMT that may be reduced by the measure. A few transportation measures are aimed at improving the emissions profile of the vehicle fleet. These measures promote alternative fuels and vehicle types. The emission reductions from these measures are based on the improved emission factors and on changes to the assumed vehicle fleet mix.

This section provides guidance for combining emission reductions from transportation measures and adjusting VMT reductions to expected GHG savings. The measure factsheets and quantification methods for individual measures follow. Use the graphic on the following page to click on an individual measure to navigate directly to the measure's factsheet.

Selecting and Combining Transportation Measures

Depending on how VMT has been quantified for a project or program, users should exercise caution when selecting transportation measures to avoid double counting VMT benefits that may already be accounted for in the model used to produce the unmitigated or baseline VMT estimate. For example, regional travel demand models are generally sensitive to built environment and transit service variables (e.g., density, proximity to transit). VMT estimates developed for a project or program that use such models may, therefore, already account for VMT reductions associated with certain measures in this Handbook (e.g., T-1, *Increase Residential Density*).

Interactions between transportation measures are complex and sometimes counterintuitive, whereby combining measures can have a substantive impact on reported emission reductions. To safeguard the accuracy and reliability of the methods, while maintaining their ease of use, the following rules should be followed when combining reductions achieved by transportation measures.

Transportation

LAND USE

- T-1. Increase Residential Density
- T-2. Increase Job Density
- T-3. Provide Transit-Oriented Development
- T-4. Integrate Affordable and Below Market Rate Housing
- T-17. Improve Street Connectivity
- T-55. Infill Development

TRIP REDUCTION PROGRAMS

- T-5. Implement Commute Trip Reduction Program (Voluntary)
- T-6. Implement Commute Trip Reduction Program (Mandatory Implementation and Monitoring)
- T-7. Implement Commute Trip Reduction Marketing
- T-8. Provide Ridesharing Program
- T-9. Implement Subsidized or Discounted Transit Program
- T-10. Provide End-of-Trip Bicycle Facilities
- T-11. Provide Employer-Sponsored Vanpool
- T-12. Price Workplace Parking
- T-13. Implement Employee Parking Cash-Out
- T-23. Provide Community-Based Travel Planning

PARKING OR ROAD PRICING/MANAGEMENT

- T-14. Provide Electric Vehicle Charging Infrastructure
- T-15. Limit Residential Parking Supply
- T-16. Unbundle Residential Parking Costs from Property Cost
- T-24. Implement Market Price Public Parking (On-Street)

NEIGHBORHOOD DESIGN

- T-18. Provide Pedestrian Network Improvement
- T-19-A. Construct or Improve Bike Facility
- T-19-B. Construct or Improve Bike Boulevard
- T-20. Expand Bikeway Network
- T-21-A. Implement Conventional Carshare Program
- T-21-B. Implement Electric Carshare Program
- T-22-A. Implement Pedal (Non-Electric) Bikeshare Program
- T-22-B. Implement Electric Bikeshare Program
- T-22-C. Implement Scootershare Program
- T-22-D. Transition Conventional to Electric Bikeshare

TRANSIT

- T-25. Extend Transit Network Coverage or Hours
- T-26. Increase Transit Service Frequency
- T-27. Implement Transit-Supportive Roadway Treatments
- T-28. Provide Bus Rapid Transit
- T-29. Reduce Transit Fares
- T-46. Provide Transit Shelters

CLEAN VEHICLES AND FUELS

- T-30. Use Cleaner-Fuel Vehicles

SCHOOL PROGRAMS

- T-40 Establish a School Bus Program
- T-56. Active Modes of Transportation for Youth

Combining Measures Across Scales

The first level of organization for the transportation measures is the scale of application. There are 19 quantified measures at the Project/Site scale that can be combined with each other and 19 quantified measures at the Plan/Community scale that can be combined with each other.[4] *The GHG reductions of transportation measures from different scales of application should never be combined.* While it may be possible that a user's project involves measures that affect vehicle trips or VMT at both scales, it is likely that combining the percent reduction from measures of different scales would not be valid. This rule does not apply to non-transportation measures that calculate the emissions reduction in terms of absolute emissions.

Combining Measures within a Subsector

The second level of organization for the transportations measures is the subsector. Transportation measures are separated into seven subsectors: Land Use, Neighborhood Design, Trip Reduction Programs, Parking Management, Transit, Parking or Road Pricing/Management, Clean Vehicles and Fuels, and School Programs.

Effectiveness levels for multiple measures within a subsector may be multiplied to determine a combined effectiveness level. Because the combination of measures and independence of measures are complicated, this Handbook recommends that measure reductions within a subsector be multiplied unless the user can provide substantial evidence indicating that emission reductions are independent of one another and that they should therefore be added. This will take the following form:

$$\text{Reduction}_{\text{subsector}} = 1 - [(1 - A) \times (1 - B) \times (1 - C)]$$

Where A, B, and C are the individual measure reduction percentages for the measures to be combined in each subsector.

Each measure has a maximum allowable reduction, discussed in the quantification methods for each measure. The user should calculate the reduction from each measure, compare it to the individual measure maximum, and use the lower value of the two in the equation above.

In addition, each subsector has a maximum allowable reduction. These were derived by combining the maximum allowable reduction of each individual non–mutually-exclusive measure within the subsector using the above formula (see table below for more details). The subsector maximum is intended to ensure that emissions are not double counted when measures within the subsector are combined. The subsector maximums are provided in the below table by scale of application.

[4] There is one additional quantified transportation measure: Measure T-30, *Use Cleaner-Fuel Vehicles*. All below discussion related to combining measures and determining maximums does not apply to this measure, which is part of the Clean Vehicles and Fuels subsector.

Scale	Subsector	Quantified Measures [a]	Subsector Maximum [b, c, d, e, f]
P/S	Land Use	5	65%
	Neighborhood Design	—	—
	Trip Reduction Programs	9	45% commute VMT
	Parking or Road Pricing/ Management	3	35%
	Transit	—	—
	School Programs	2	72% school VMT
P/C	Land Use	1	30%
	Neighborhood Design	10	10%
	Trip Reduction Programs	1	2.3% commute VMT
	Parking or Road Pricing/ Management	1	30%
	Transit	6	15%
	School Programs	—	—

P/S = project/site; P/C = plan/community; VMT = vehicle miles traveled.

[a] Excludes Measure T-30, *Use Cleaner-Fuel Vehicles*, within the Clean Vehicles and Fuels subsector and all supporting or non-quantified measures from other subsectors.

[b] — = no measure within the subsector at the specified scale.

[c] Where a subsector consists of only one measure, the subsector maximum listed is the individual measure maximum.

[d] Most maximums were conservatively rounded down to the nearest multiple of five or whole number.

[e] Measure T-1 and Measure T-2 were assumed to be mutually exclusive for the purpose of deriving a project's single land use type maximum emissions reduction. More specifically, residential density (T-1) only applies to residential development, and job density only applies to commercial development (T-2). Similarly, Measure T-26, Measure T-27, and Measure T-46 were assumed to be mutually exclusive with Measure T-28 for the purpose of deriving a plan/community's total transit-related emissions reduction. Measure T-28 accounts for the VMT reduction associated with increased transit frequency (T-26), station improvements like shelters (T-46) and decreased transit travel time from transit supportive roadway treatments (T-27). It was assumed that bus rapid transit (BRT) (T-28) would cover all of the community's transit routes, and therefore no additional frequency, station, or time improvements would be attainable (T-26, T-27, and T-46).

[f] Measures within the Trip Reduction Programs and School Programs primarily reduce VMT from *employee commute* trips and *student commute* trips, respectively, whereas all other measures reduce VMT from *all* trips associated with the relevant land use type.

The user should calculate the reduction from each subsector, compare it to the corresponding sector maximum, and use the lower value of the two.

Combining Measures Across Subsectors

There is limited research directly analyzing the combined VMT impact on a project/site or plan/community from implementation of all, or a majority, of the non–mutually-exclusive transportation sector measures provided in this Handbook. However, a University of California, Davis study compared household VMT across different place types in California and found that the difference in average VMT in single-family suburban neighborhoods and central city neighborhoods was approximately 70 percent.[5] Central city neighborhoods are more likely to have implemented transportation strategies like those measures included in the Handbook, when

[5] Salon, D. 2014. *Quantifying the Effect of Local Government Actions on VMT.* Institute of Transportation Studies, University of California, Davis. Prepared for the California Air Resources Board and the California Environmental Protection Agency. February. Available: https://ww2.arb.ca.gov/sites/default/files/classic/research/apr/past/09-343.pdf. Accessed: October 2021.

compared to suburban neighborhoods. The Handbook therefore adopts 70 percent as a maximum for the combined VMT impact from the following four subsectors: Land Use, Neighborhood Design, Parking or Road Pricing/Management, and Transit.

$$\text{Reduction}_{\text{multi-subsector}} = 1 - [(1 - \text{Land}) \times (1 - \text{Design}) \times (1 - \text{Parking}) \times (1 - \text{Transit})] \leq 70\%$$

Note that this multi-subsector maximum purposefully excludes the Trip Reduction Program subsector. This is because measures in the Trip Reduction Program subsector are often implemented at the Project/Site scale based on the individual employer and are not as directly correlated with place type as the other subsectors. For example, all central city neighborhoods have a high residential and commercial density (i.e., Measure T-1 and Measure T-2 from the Land Use subsector), and most single-family suburban neighborhoods have low density. Conversely, not all employers in a central city neighborhood provide their employees with discounted transit passes (Measure T-9 from the Trip Reduction Program subsector), and the same is equally likely for the much smaller group of employers in a single-family suburban neighborhood.

Limitations of Maximums and Caps

The words *maximum* and *cap* are used interchangeably to describe either the highest percent reduction in GHG emissions or the highest expected value for a variable in the GHG reduction formula. Each subsector has a maximum allowable reduction and individual measures have a maximum allowable reduction, which is often based on one or more of the capped GHG reduction variables. In most instances, these values are a rule of thumb, or practical approximation, to limit the unrealistic influence of multiplicative measure variables. Where the maximum is derived based on a more precise methodology (e.g., research results), the source is cited. Users should always confirm the appropriateness of these maximums for their project.

Adjusting VMT Reductions to Emission Reductions

Most of the transportation measures in this Handbook reduce GHG emissions and criteria pollutants (co-benefit) by reducing the source metric of VMT.[6] The below equation highlights the main variables used to calculate VMT in a study area. Note that VMT decreases if any of the following occurs: (1) vehicle ownership declines, (2) vehicle trips are reduced, (3) vehicle trip lengths are reduced, or (4) any combination of these three variables.

$$\text{VMT} = \frac{\text{vehicles}}{\text{study area}} \times \frac{\text{trips}}{\text{vehicle} \cdot \text{day}} \times \frac{\text{distance (miles)}}{\text{trip}} = \frac{\text{miles}}{\text{study area} \cdot \text{day}}$$

Vehicles emit pollutants during all hours of the day. The magnitude of these emissions varies with the activity phase, such as running on the road, idling while stationary, sitting outside in the sun (evaporative), or starting up. The quantification methods presented in this Handbook account for emissions that occur during the three major emission processes of running, evaporation, and starting.[7]

[6] Exceptions include Measures T-14, *Provide Electric Charging Infrastructure*, and T-30, *Use Cleaner-Fuel Vehicles*.

[7] A fourth emission process is idling. EMFAC estimates idle exhaust emissions only for heavy-duty vehicles that idle for extended periods of time while loading or unloading goods. This document analyzes emissions primarily from passenger vehicles and thus focuses on the three relevant emission processes of evaporation, starting, and running.

Emissions generated by these processes are determined, in part,[8] by the above VMT variables: (1) emissions from evaporation are a factor of vehicle ownership, (2) emissions from starting are a factor of vehicle ownership and number of vehicle starts (i.e., trips), and (3) emissions from running are a factor of vehicle ownership and number of vehicle trips and distance per trip (i.e., VMT).

$$Emissions_{total} = Emissions_{evap} + Emissions_{start} + Emissions_{run}$$

$$Emissions_{evap} = \frac{\text{vehicles}}{\text{study area}} \times \frac{\text{pollutant mass (grams)}}{\text{vehicle}\cdot\text{day}} = \frac{\text{grams}}{\text{study area}\cdot\text{day}}$$

$$Emissions_{start} = \frac{\text{vehicles}}{\text{study area}} \times \frac{\text{trips}}{\text{vehicle}\cdot\text{day}} \times \frac{\text{pollutant mass (grams)}}{\text{trip}\cdot\text{day}} = \frac{\text{grams}}{\text{study area}\cdot\text{day}}$$

$$Emissions_{run} = \frac{\text{vehicles}}{\text{study area}} \times \frac{\text{trips}}{\text{vehicle}\cdot\text{day}} \times \frac{\text{miles}}{\text{trip}} \times \frac{\text{pollutant mass (grams)}}{\text{distance (miles)}} = \frac{\text{grams}}{\text{study area}\cdot\text{day}}$$

GHG and criteria pollutant reductions achieved by transportation measures are primarily presented in terms of a percent reduction, where the total emissions reduction was determined based on a ratio comparison to the VMT reduction. In other words, if a measure reduces VMT by some percent, the total emissions are reduced by the same percent (or a fraction of that percent, as described below). As discussed above, VMT can be reduced by decreasing any of the three variables of vehicle ownership, number of vehicle trips, and trip distance. The ratio comparison between reductions in VMT and emissions depends on the pollutant and which VMT variable(s) decrease with implementation of a transportation measure.

1. *Less vehicle ownership*. If a transportation measure reduces VMT by decreasing vehicle ownership, the measure would decrease running, starting, and evaporative emissions by the same rate.[9] The measures where this applies are Measures T-15, *Limit Residential Parking Supply*, and T-16, *Unbundle Residential Parking Costs from Property Cost*, where the VMT reduction is a function of avoided vehicle ownership in residents disincentivized to park offsite or pay the separate cost of parking for a vehicle. For these measures, there is a 1:1 relationship between reductions in VMT and emissions because these measures reduce all emission processes at the same rate, not just running emissions.

2. *Fewer vehicle trips*. If a transportation measure reduces VMT by decreasing the number of vehicle trips, the measure would decrease running emissions and starting emissions by approximately the same rate. This applies to all transportation measures except Measures T-14, *Provide Electric Vehicle Charging Infrastructure;* T-15, *Limit Residential Parking Supply;* T-16, *Unbundle Residential Parking Costs from Property Cost;* and T-30, *Use Cleaner-Fuel Vehicles*. This is because each measure would result in, at minimum,[10] fewer vehicle trips by promoting alternative modes of transportation in place of single-occupancy vehicles.

   These measures would not decrease evaporative emissions, which are a function of vehicle ownership. However, this does not affect the ratio comparison between reductions in VMT and GHG emissions because there are no evaporation GHG emissions (i.e., 100 percent of

[8] Vehicle emissions are also a function of the chosen analysis year, project location, and fleet mix. When using EMFAC, future year emissions decline over time, reflecting assumed changes in fleet mix for the location and cleaner engine and fuel technologies.

[9] Assuming emission factor variables are held constant.

[10] Many of these measures also result in shorter vehicle trips. In these instances, the VMT reduction is either largely a function of the reduction in vehicle trips or is an equal function of the reduction in vehicle trips and the reduction in trip distances. There are no measures where the VMT reduction is largely a function of the reduction in trip distances with a lesser contribution from the reduction in vehicle trips.

CO_2, CH_4, and nitrous oxide (N_2O) from vehicles are from running and starting). This is also true for nitrogen oxides (NOx) particulate matter (PM2.5 and PM10), carbon monoxide (CO), and sulfur dioxide (SOx). Therefore, for these measures and pollutants, there is a 1:1 relationship between reductions in VMT and emissions.

Reactive organic gases (ROG) from vehicles include not only running and starting emissions, but also evaporative emissions.[11] Running and starting ROG emissions represent approximately 87 percent of total ROG emissions in passenger vehicles.[12] This adjustment factor should be applied when converting the percent GHG reduction to the percent reduction in total ROG emission.

$$\% \text{ reduction in ROG emissions} = \% \text{ reduction in GHG} \times 87\%$$

This is noted in the co-benefits section of *Improved Air Quality* for each applicable transportation measure.

3. *Shorter vehicle trips*. If a transportation measure reduces VMT by only decreasing the distance of vehicle trips, the measure would not reduce starting or evaporative emissions. There are no transportation measures in this Handbook where this scenario occurs and, therefore, an adjustment factor is not developed.

The criteria pollutants CO, NO_2, SO_2, and PM are local pollutants that can potentially affect populations near the emissions source. Accordingly, measures that reduce localized criteria pollutant emissions can improve ambient air quality. Measures that reduce emissions of ozone precursors (NOx and ROG), which are regional pollutants, can improve regional air quality.

Note that the Handbook's use of a ratio comparison of VMT reduction to GHG and criteria pollutant reductions makes two key assumptions that may not be valid for every user's project. It is important users consider the validity of these assumptions on a project-by-project basis and either (1) perform any post-processing to the emissions reductions achieved by the transportation measures to better reflect their project conditions, or (2) provide a qualitative disclaimer about the accuracy of the estimated reductions considering the below assumptions.

1. *Vehicle class is assumed to remain unchanged with implementation of a measure*. Say a user is interested in calculating the plan/community-level GHG reduction from Measure T-22-B, *Implement Electric Bikeshare Program*. The user has community-level VMT without the measure and elects to calculate community-wide mobile emissions using EMFAC. The user calculates in EMFAC that the existing percent of the community VMT by vehicle class is 75 percent light-duty vehicles and 25 percent non-light-duty vehicles. In this example, the average emission factor for light-duty vehicles is 250 grams CO_2 per mile and for non–light-duty vehicles is 400 grams CO_2 per mile. The average community emission factor, as weighted by VMT, would be 288 grams per mile [(75% X 250 grams CO_2 per mile) + (25% X 400 grams CO_2 per mile)]. Users then estimate vehicle emissions prior to implementation of Measure T-22-B by applying this average vehicle emission factor to their community-level VMT.

   The user then implements Measure T-22-A, *Implement Pedal (Non-Electric) Bikeshare Program*, and reduces GHG emissions from vehicle travel by 4 percent by replacing vehicle

[11] See *EMFAC2017 User's Guide* for more detail on these emission processes. Available: https://ww3.arb.ca.gov/msei/downloads/emfac2017-volume-i-users-guide.pdf.

[12] Combined emissions from the EMFAC vehicle types of LDA, LDT1, and LDT2.

trips with bikeshare trips. The majority of those replaced vehicle trips are private trips as light-duty vehicles. As a result, the percent of the community VMT by vehicle class is now 70 percent light-duty vehicles and 30 percent non–light-duty vehicles, effectively increasing the community average vehicle emission factor, as weighted by VMT, from 288 grams per mile to 295 grams per mile [70% X 250 grams CO_2 per mile) + (30% X 400 grams CO_2 per mile)]. This increase in the community average vehicle emission factor lessens the GHG reduction that would be achieved from reduced vehicle trips.

Conversely, the circumstances could be such that a measure increases the GHG reduction that would be achieved from reduced vehicle trips. For example, Measure T-22-A may replace existing vehicle trips that are primarily from more emissions-intensive non–light-duty vehicles (e.g., transit buses). In this case, the percent of the community VMT by the less–emissions-intensive light-duty vehicle would be higher, reducing the community average vehicle emission factor. This decrease in the community average vehicle emission factor would increase the GHG reduction that would be achieved from reduced vehicle trips.

The Handbook method cannot predict or know how each measure could affect the user's specific fleet mix. Therefore, the fleet mix is assumed to remain constant before and after implementation of all transportation measures.

2. *Vehicle speeds are assumed to remain unchanged with implementation of a measure*. The logic of this assumption is similar to the first assumption. Say a user is interested in calculating the plan/community-level GHG reduction from Measure T-20, *Expand Bikeway Network*. The user elects to calculate community-wide mobile emissions prior to implementation of the measures using EMFAC and aggregated vehicle speeds. In this example, EMFAC aggregates the vehicle speeds in the user's community at approximately 30 miles per hour (mph).[13] The user implements Measure T-20 and expansion of the bikeway network reduces the average vehicle speed to approximately 25 mph. Because vehicles are slightly more GHG emissions-intensive at 25 mph compared to 30 mph, the GHG reduction achieved by the measure would be less if the impact of vehicle speeds were included in the quantification method.

   Conversely, the circumstances could be such that a measure increases the GHG reduction that would be achieved from reduced vehicle trips. For example, Measure T-11, *Provide Employer-Sponsored Vanpool*, replaces private vehicle trips with shared vanpool trips, reducing the number of cars on the road. If roadways are currently congested and causing vehicles to move at low speeds, implementation of this measure could alleviate roadway congestion and increase vehicle speeds to a speed in which they are less GHG emissions intensive. The decrease in the community average vehicle emission factor would increase the GHG reduction that would be achieved from reduced vehicle trips.

   The Handbook method cannot predict or know how each measure could affect vehicle speeds under the various use cases. Therefore, the vehicle speeds are assumed to remain constant before and after implementation of all transportation measures.

[13] Vehicle running emission factors are, in part, dependent on vehicle speed. Vehicles are generally more emissions-intensive at speeds that are very low (e.g., 5 mph) and very high (e.g., greater than 70 mph), though this varies by pollutant and vehicle class.

Use of Transportation Quantification Methodologies for Senate Bill 375 Compliance

As described in Appendix B, *Federal and State Planning Framework,* Senate Bill (SB) 375 requires metropolitan planning organizations (MPOs) to incorporate a SCS in their regional transportation plans (RTPs) and submit it to the California Air Resources Board (CARB) for review. The goal of the SCS is to reduce regional passenger vehicle VMT and associated GHG emissions through land use and transportation planning. CARB requires MPOs quantify the passenger vehicle VMT reductions achieved by their SCSs using a specific method. It is therefore not recommended that MPOs use the transportation measure quantification methodologies found in this Handbook when preparing their SCSs.