Appendix K.

LA MTA Congestion Mitigation Fee Tool – GHG Emissions Calculator

CAMBRIDGE
SYSTEMATICS

LA MTA Congestion Mitigation Fee Tool - GHG Emissions Calculator

Draft Methodology Documentation

technical

memorandum

prepared for

Los Angeles County Metropolitan Transportation Authority

prepared by

Cambridge Systematics, Inc.

September 27, 2010

www.camsys.com

technical memorandum

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1.0 Introduction

At the behest of the Los Angeles County Metropolitan Transportation Authority (MTA), Cambridge Systematics (CS) developed a set of sketch-planning tools designed to estimate the potential greenhouse gas (GHG) reduction benefits of congestion mitigation fee (CMF) candidate projects included in the web-based *Fee Revenue and Growth Forecast Calculator*.

A diverse range of national, state, and regional tools and research were referenced to support the development of the tool, including CS' *Moving Cooler* report and the U.S. Department of Transportation (U.S. DOT) Report to Congress, *Transportation's Role in Reducing U.S. GHG Emissions*. Significant adaptations and refinements were made to these existing tools and research findings in order to ensure these methodologies are context sensitive to MTA regional features and produce the most reasonable results possible. CS used the following four-step process to adapt these various tools and research into an analytical tool for use in Los Angeles County:

1. **Define the context of the MTA region.** The accurate GHG analysis of any individual project or set of projects relies on a relationship to the location context in which these projects are deployed. This step also involved analyzing and categorizing projects included in the *Fee Revenue and Growth Forecast Calculator* to ensure that methodologies were available for the vast majority of projects that might be included in a Los Angeles County CMF program.
2. **Adapt the *Moving Cooler* tools to regional analysis.** The *Moving Cooler* methodology evaluates the efficacy of more than 50 transportation and land use strategies, and estimated synergies between individual strategies when bundled. The methods rely on empirical data and experience from research projects. CS updated these methods to pivot off the *Moving Cooler* analysis while applying region-specific data. As appropriate, additional region- and/or state-specific tools were incorporated into the analysis. These data and resources were applied to the preliminary list of CMF-eligible projects, and 10 separate project methodologies were identified for development.
3. **Develop and test a draft analytical tool.** CS developed and tested an interactive sketch-planning model in Excel spreadsheet format, allowing for on-the-fly individual project GHG emission reduction analysis, pursuant to a set of user-defined inputs.
4. **Develop and test a web-based GHG analysis tool**. CS adapted the spreadsheet-based sketch-planning tools into a user-friendly, web-based module to be used within the *Fee Revenue and Growth Forecast Calculator's* Geographic Information System (GIS) tool. The finished tool allows cities and subregions to test individual GHG reduction scenarios for one or more

CMF projects specified by Los Angeles County jurisdictions. The spreadsheets and web-based tool tested five identical sets of inputs by project type to validate consistency between the spreadsheet and web-based coded methodologies.

Each of the 10 project types available for analysis within the web tool are subject to specific user-defined inputs, constraints, and calculations, as detailed in Section 2.0 of this technical memorandum. While the 10 project type methodologies are able to analyze the GHG impacts of the vast majority of preliminary projects entered in the CMF web tool, some unique projects may not be suitable for these analyses. However, for the vast majority of eligible projects, the tool provides a common platform to estimate GHG reduction benefits and compare results within and across different geographic and political boundaries. Section 3.0 details two project types not included in this version of the web tool. Section 4.0 outlines the approach for developing carbon dioxide (CO_2) emission factors via the California Air Resources Board's (CARB) Emissions Factors (EMFAC) model; and the process for applying emissions factors in combination with estimates of changes in travel behavior (e.g., vehicle miles traveled (VMT), speed, and delay) to determine CO_2 emission reductions. Section 5.0 provides a summary of the major limitations of the tool as currently designed, and identifies next steps for expanding the tool's calculation abilities.

The references are provided in Appendix A. Appendices B, C, and D provide additional details regarding factors used in the calculation of GHG emission reductions for each project type. Appendix B presents a map of SCAG-defined area types; Appendix C includes the LA MTA model free-flow speed and capacity lookup table; and Appendix D presents all constants and assumptions, along with the citation and justification for their use in the project calculations.

2.0 Technical Documentation by Project Type

This section presents the project type objective, evaluation constraints, inputs, assumptions, and methodologies supporting the calculation of GHG emission reduction benefits of 10 unique types of CMF projects:

1. Roadway capacity,
2. Interchange capacity,
3. Intersection improvement,
4. System operations,
5. Grade separation,
6. Bike/pedestrian,
7. Bike/pedestrian and transit,
8. Transit expansion,
9. Park-and-ride, and
10. Managed lanes.

Sketch-planning tools are used to calculate emission reductions for all projects within each project type. It is important to note that there are some travel model and microsimulation-based approaches not included here that are considered extremely effective for simulating and calculating emission reductions on a project-by-project basis. The web-based platform is currently unable to accommodate this precision of detail at the project level without performing many costly and time consuming model runs. Nevertheless, these project-type methodologies offer a reasonable approximation of GHG impacts given the limited details provided by CMF project descriptions.

The design of the equations, lookup tables, and overall calculation process is transparent, while maintaining technical validity. The critical lookup tables and background information supporting the calculations and their location in this document are listed below:

1. **Roadway Capacity**
   a. SCAG area type map (Appendix b)
   b. LA MTA model speed and capacity lookup table (Appendix C)
   c. LA MTA model speed-flow curve equations (Section 2.1)
   d. EMFAC emission factors (Section 4.0)
2. **Interchange Capacity**
   a. LA MTA model speed and capacity lookup table (Appendix C)
   b. LA MTA model speed-flow curve equations (Section 2.1)
   c. EMFAC emission factors (Section 4.0)

3. **Intersection Improvement**
   a. LA MTA model speed and capacity lookup table (Appendix C)
   b. EMFAC emission factors (Section 4.0)
4. **Systems Operations**
   a. California DOT's (Caltrans) Traffic Light Synchronization Program (TLSP) evaluation algorithms (Section 2.4)
   b. EMFAC emission factors (Section 4.0)
5. **Grade Separation**
   a. EMFAC emission factors (Section 4.0)
6. **Bike/Pedestrian**
   a. ADT adjustment factor lookup table (Appendix D, Section 2.6)
   b. Activity center credits (Appendix D)
   c. EMFAC emission factors (Section 4.0)
7. **Bike/Pedestrian and Transit**
   a. ADT adjustment factor lookup table (see Appendix D, Section 2.6)
   b. Activity center credits (Appendix D)
   c. Increase in transit trips by area type and transit mode (Section 2.7)
   d. VMT per capita by area type (Section 2.7)
   e. SCAG area type map (Appendix B)
   f. EMFAC emission factors (Section 4.0)
8. **Transit Expansion**
   a. Increase in transit trips by area type and transit mode (Section 2.7)
   b. VMT per capita by area type (Section 2.7)
   c. SCAG area type map (Appendix B)
   d. EMFAC emission factors (Section 4.0)
9. **Park-and-Ride**
   a. Average weekday parking utilization (Table 2.12)
   b. EMFAC emission factors (Section 4.0)
10. **Managed Lanes**
    a. LA MTA model speed-flow curve equations (Section 2.1)
    b. EMFAC emission factors (Section 4.0)

Each existing CMF project-type calculation was first developed and tested in a spreadsheet format. Five unique test cases were evaluated for each project type in the spreadsheets, and then retested in the web-based platform in order to validate the calculations.

All project-level calculations are first estimated at the daily level, and then annualized based on a factor of 250 days.[1] All emission factors and calculations are presented in Section 4.0.

2.1 ROADWAY CAPACITY

Overview and Project Types

This project type evaluates those roadway capacity projects that add new capacity by widening an existing facility, or by building or extending a new roadway. The evaluation requires the user to specify a facility type, which defines the physical characteristics of the facility under improvement; and an area type, which describes the area where the facility is located. Emission reductions from these projects are derived from increased average vehicle speeds due to capacity expansion and improved traffic flow rates resulting from decreased congestion. Emission reductions vary by the type of facility under expansion and the location of the facility.

Methodology Limitations

This approach is used for projects involving capacity expansion through the addition of additional travel lanes. Construction of new access lanes or connecting facilities can only be evaluated using this method if the existing average speed on alternative routes is known; and the anticipated traffic volume due to the construction of the proposed facility can be estimated from a study, modeling exercise, or analysis based on valid assumptions. Turning lanes, center-turn lanes, and capacity additions at intersections cannot be evaluated using this method. Emission reductions benefits are calculated for the peak period, and it is assumed that benefits are negligible during off-peak hours.

This approach does not account for the impact of diverted traffic resulting from the capacity expansion. Enhanced capacity in one corridor may act to move trips from a parallel corridor with higher congestion. It is assumed that, at a regional level, the impact of diverted traffic results in no net change in GHG emissions.

It is further assumed that the potential impact of induced travel is negligible due to the minor impact of these projects on cumulative regional travel.

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[1] There are approximately 250 workdays in a year.

User-Defined Inputs

The methodology requires a set of project-specific, user-defined inputs presented in Table 2.1.

Table 2.1 Roadway Capacity Project User-Defined Inputs

User-Defined Input	Default Values	Input Guidance
Average Annual Weekday Traffic (AAWT) Volume		• Enter total daily weekday traffic on the corridor
Facility type		• Select from Interstate, Expressway, Primary, or Secondary arterial type • Definitions inherited from the Southern California Association of Governments (SCAG) travel demand model
Area type		• Select from Central Business District (CBD), Urban, Suburban, Mountain, and Rural area types • Definitions based on traffic analysis zone attributes and inherited from the SCAG travel demand model (see Appendix A)
Total number of lanes (existing, in 2010)		• Enter total number of lanes before improvement in one direction in case of a divided facility, and in both directions in case of an undivided facility • Intersection turn pockets are represented by ½ lanes
Total number of lanes (proposed, by 2020)		• Enter total number of lanes after improvement in one direction in case of a divided facility, and in both directions in case of an undivided facility
Project Length (miles)		• Enter total length of the project
Truck percentage		• Enter share of trucks as a fraction of total corridor traffic

Methodology

Emission reductions due to capacity expansion projects are a result of improved traffic flow as a result of added capacity. The extent of improvement is based on the type of facility being improved and area characteristics representing travel intensity. Speed and capacity information by facility type and area types have been obtained from the MTA's travel demand model (see Appendix B). Travel speeds on the facility's before-and-after capacity expansion are calculated using speed-flow curves from the MTA's travel demand model. Speed flow equations used in the MTA travel demand model are as follows:

$S = s0/(1+1.5\ (x)^{6})$ for Freeways, high-occupancy vehicle (HOV), and Toll Facilities

$S = s0/(1+0.15\ (x)^{5})$ for Other Facility Types

Where:

$s0$ = Free-flow speed; and

x = Volume to capacity ratio.

Travel speeds are calculated for peak periods and only during weekdays, since it is conservatively assumed that the speed variations during the off-peak periods and weekends are marginal. The methodology calculates separate emissions reduction rates for trucks and cars, pursuant to a user-defined estimate of the average share of trucks relative to total traffic on the segment.

2.2 INTERCHANGE CAPACITY

Overview and Project Types

Interchange capacity projects are those that improve capacity through existing interchange and ramp improvements, either by adding lanes to existing ramps, or by improving traffic flow conditions by improving vehicle delay at off-ramps serviced by a downstream-signalized intersection. The evaluation methodology incorporates emissions reductions due to improvements in traffic flow for both on-ramps and off-ramps.

Methodology Limitations

In order to accommodate as many types of interchanges as possible, the methodology addresses improvements by classifying them for on-ramps and off-ramps. Otherwise, the project input will be dependent on the type of intersection; opening the door to a number of possibilities, which makes the data input complex for a sketch-planning approach. New ramp access connections cannot be evaluated using this method.

User-Defined Inputs

The methodology requires the set of project-specific, user-defined inputs presented in Table 2.2.

Table 2.2 Interchange Capacity Project User-Defined Inputs

User-Defined Input	Default Values	Input Guidance
On-ramp 1 AAWT		• Enter average annual weekday traffic on the first on-ramp
On-ramp 2 AAWT		• Enter average annual weekday traffic on the second on-ramp
On-ramp 1 existing number of lanes		• Enter total number of lanes before improvement on the on-ramp (2010) • Intersection turn pockets are represented by ½ lane
On-Ramp 2 existing number of lanes		• Enter total number of lanes before improvement on the off-ramp
On-ramp 1 capacity enhancement (added # of lanes by 2020)		• Enter total number of lanes after improvement on the first on-ramp
On-ramp 2 Capacity Enhancement (added # of lanes by 2020)		• Enter total number of lanes after improvement on the second on-ramp

Methodology

Emission reductions from interchange improvements can be classified from two different types of improvements: 1) adding capacity to existing ramps to improve traffic flow, and thereby improve speeds and reduce emissions; and 2) reducing delay on interchange off-ramps due to traffic control (such as a signalized intersection) downstream of the off-ramp.

Emission reductions from improvements to interchanges are achieved through providing improved access to arterial streets or other connecting highway facilities through ramp improvements. Turn lanes at the traffic signal downstream of the off-ramp from the interchange are considered to be one-half the capacity of a single lane. Generalized ramp capacity and average speeds are obtained from LA MTA's travel demand model output.

The methodology is similar to providing additional capacity, resulting in improved speed and level of service (LOS). Speed-flow curves equations from MTA's travel demand model are used for calculating the travel time taken to navigate the ramps before and after the improvement.

$$TC = T0 * (1 + 1.50*(X)^6)$$

Where:

TC = Congested travel time;

$T0$ = Free-flow travel time; and

X = Volume to capacity ratio.

Travel time before and after the improvement is translated to average speed. Emission factor lookups are applied based on the before-and-after improvement speeds and ramp VMT to estimate total change in emissions.

Improvements downstream of an off-ramp may include changes to signal timing and phasing, or adding turn pockets and right-turn phases to reduce intersection delay. Control delay per vehicle can be calculated by an intersection delay study, or by estimation on the basis of traffic arrival patterns and progression criteria. Table 2.3 provides guidance for determining intersection LOS and control delay per vehicle.

The estimate of total delay savings as a result of an intersection improvement at the ramp termini uses the Section following formula:

$$d_1 = \frac{0.5C\left(1 - \frac{g}{C}\right)^2}{1 - \left[\min(1, X)\frac{g}{C}\right]}$$

Where *C* = is the cycle length, *g/C* = is the green time to cycle ratio = 0.5 (for simplicity) and X is the highest volume to capacity ratio of any turning movement or a lane group at the intersection. This approach is consistent with the calculation for intersection project type #3 as presented in Section 2.3.

The improvement in delay experienced per vehicle due to a change in capacity at the intersection is transformed into total delay in vehicle hours and thereby used for estimation of emission reductions.

Ultimately, total emission savings for this project type is a product of both the savings from improving ramp capacity and the savings from reduced intersection delay at ramp termini.

2.3 INTERSECTION IMPROVEMENT

Overview and Project Types

The model is designed to evaluate at-grade intersection improvement projects. CO_2 emission reductions due to intersection improvements are a result of the reduced delay navigating the intersection– – either due to idling at the red light, or due to deceleration and queuing that occurs at the intersection. The methodology to estimate the reduction in greenhouse gas emissions includes three types of intersection improvements leading to emission reductions:

- **Type 1.** New Signal. An unsignalized intersection approaching failure due to intolerable levels of delays is improved to a signalized intersection with an acceptable level of service.

- **Type 2.** New Turning Phase. Enabling a specific turn or movement at the intersection that was non-existent or making a permissive turn into a protected turn by changing the signal phasing and/or timing.
- **Type 3.** Improved Intersection Capacity. Changes to the signalized intersection positively impacting level of service, including improvements to geometry, approach redesign, or new lanes.

In each case, average reduction in delay per vehicle due to the improvement is estimated to determine the emission reduction benefits as a result of the improvement. Intersection delay can be measured by conducting intersection delay studies or by estimation with input data like signal cycle length and effective green times for critical movements.

This methodology strives to hit the middle-ground between conducting a full intersection delay analysis for determining delay before and after improvement, and conducting a field study for obtaining delay parameters. To achieve this, the methodology makes some key assumptions. Typically, agencies perform delay and LOS calculations as part of an intersection delay study or intersection LOS analysis. In the absence of such detailed data, delay can be estimated by arrival patterns and LOS data. Some of this data is already available from intersection studies and corridor studies, or might be maintained by the traffic or public works departments charged with maintaining the signals.

A major overarching assumption is that the design methodology considers the signals as pre-timed, given the difficulty of accounting for the dynamics of changes to signal times and phases under an actuated setting.

Methodology Limitations

The intersection improvement methodology calculates delay at a single intersection level, and is not equipped to estimate improvement benefits for multiple intersections or systemwide improvements. Intersection delay studies are the best source for delay measurements, if available. In the absence of observed intersection delay information, guidance to estimate delay is provided based on arrival types or LOS, as presented in Table 2.3. This methodology is not applicable in case of a staggered (five-legged or more) intersection.

In the absence of accurate delay data, estimation through vehicle approach and progression should be made as accurately as possible. LOS corresponding to delay windows may only be used to approximate control delay due to the difference in lower and upper bounds of each LOS (for example, LOS F corresponds to a delay between 55 to 80 seconds per vehicle, which might not be precise enough to provide an accurate estimation of emission reduction benefits).

User-defined input data like peak hour volumes, cycle length, and approach capacity are the minimum required to support the calculation of intersection improvement emission reduction benefits. Available traffic data and signal operating plans from a traffic management data center or a public works/transportation department is recommended. If unavailable, observed delay or intersection LOS can be used as an approximation. In order to calculate delay reduction benefits, a number of key assumptions are required to simplify the calculations so that the number of inputs is manageable.

Note: The web-based version of the GHG Emissions Calculator allows users to assign one or more of the intersection improvement project types listed above. In project definitions where both a new phase and added capacity are included (i.e., a mix of project type 2 and 3), the following approach is recommended:

1. For projects adding only turn-lane capacity and new turn phasing, only apply the project type 2 approach, entering the new number of turn lanes as an input.
2. For projects adding both turn-lane and through-lane capacity, apply both the project type 2 and project type 3 approach separately.

User-Defined Inputs

The three unique intersection project approaches require the set of project-specific, user-defined inputs presented in Table 2.3.

Table 2.3 Intersection Improvement Project User-Defined Inputs

User-Defined Input	Default Values	Input Guidance
1. Unsignalized (2-way of 4-way stop) to Signalized Intersection		
Area Type		Five options are available (CBD, Urban, Suburban, Mountain, Rural)
Peak Hour Volume (Approach Street 1 and 2)		Enter the average weekday peak hour volume for each intersection approach[2]
Total number of lanes (Street 1 and Street 2)		Note: Each turn lane, auxiliary lane or reversible lane equals 1/2 lane. Input total lanes for both approaches of the street.
Facility Type (Street 1 and Street 2)		Four options are available (Interstate, Expressway, Primary, Secondary)
Proposed Signalized Intersection Cycle Length (sec)	60 – 120	Guidance based on FHWA signal timing manual (see Table 2.4)
Peak Hour Intersection Delay before Improvement (s/veh)	50	50 sec. per vehicle is the default assumption for LOS F at unsignalized intersections. Higher values may be entered if supported by a recent study.

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[2] If only average daily traffic is known, peak-hour volumes can be approximated by applying a factor of 0.1 (regional average).

User-Defined Input	Default Values	Input Guidance
2. New or Protected Turn Phasing at Existing Signalized Intersection		
Type of Turn Affected by Project		Input the turn movement (left or right) enabled by the new phase. Project approach can measure the benefit of adding a single phase only.
Proposed Total Cycle Length (sec) (including impact from new or extended turn phases)	60 – 120	Guidance based on FHWA signal timing manual (See Table 2.4)
Total number of turn lanes on improved turn movements		The total number of turn lanes for all of the improved turn movements. For example, if 2 left turns at the intersection are being improved, each with 1 turn lane, the user should enter 2.
3. Improvement in Overall Intersection Capacity		
Area Type		Five options are available (CBD, Urban, Suburban, Mountain, Rural)
Facility Type (Street 1 and Street 2)		Four options are available (Interstate, Expressway, Primary, Secondary)
Total number of lanes (Street 1 and Street 2)		Note: Each turn lane, auxiliary lane or reversible lane equals 1/2 lane. Input total lanes for both approaches of the street.
Total number of lanes after improvement (Street 1 and Street 2)		Note: Each turn lane, auxiliary lane or reversible lane equals 1/2 lane. Input total added lanes for both approaches of the street.
Peak Hour Volume (Approach Street 1 and 2)		Enter the average weekday peak hour volume for each intersection approach
Existing Cycle Length (sec)	60-120	See signal complexity guidance from FHWA Signal Timing Manual (see Table 2.4)

Table 2.4 FHWA Signal Timing Manual Reference

Signal Complexity	Commonly Assumed Cycle Lengths
Permissive left turns on both streets	60 seconds
Protected left turns, protected-permissive left turns, or split phasing on one street	90 seconds
Protected left turns, protected-permissive left turns, or split phasing on both street	120 seconds

Source: FHWA Traffic Signal Timing Manual, 2008.

Methodology

Intersection improvements that provide additional turn lanes, better geometric design, improved signal timing and phasing can reduce vehicle delay in navigating the intersection. This delay reduction results in lower vehicle emissions due to less vehicle time spent decelerating, accelerating, or idling. Existing vehicle hours of delay for each intersecting street (by each approach) must be estimated separately, either via an intersection delay study or data from a traffic management center. Alternatively, estimation through vehicle approach and progression should be instrumental in estimating the average delay for each approach, and thereby for intersecting streets.

Delay at the intersection is calculated given the delays for individual approaches and flow rates as follows:

$$\frac{\sum_{i=1}^{n}\left(v_i \cdot d_i\right)}{\sum_{i=1}^{n} v_i}$$

Where:

d = Delay for the approach;

v = Approach flow rate (vehicles per hour); and

n = Number of approaches to the intersection.

This reduction in average delay per vehicle approaching the intersection equates to less time spent idling, where CO_2 emission rates are highest. Since control delay takes into consideration the time elapsed for deceleration, queuing, and idling, the difference in travel speeds for noncongested conditions before-and-after improvements are not included in the GHG reduction calculation. The total change in vehicle hours of delay at the intersection, before and after the improvement, is calculated as follows:

$$\Delta D_{int} = D_{intnb} – – D_{intb}$$

Where:

D_{intnb} = Total delay at the intersection for the no-build condition; and

D_{intb} = Total delay at the intersection for the build condition.

The change in delay (ΔD_{int}) is multiplied by the idle CO_2 emissions factor (g/hr) to estimate emission reductions.

Project Type #1– – New Signal

For estimating the delay at a planned signalized intersection, short of obtaining basic design parameters of the intersection including turning movements and the lane configuration changes, the user is prompted to provide peak hour volumes for intersecting streets, respective capacity at the intersection and the total signal cycle length at the intersection. Delay at the intersection is calculated using the following formula (this formula is used within each project type approach):

$$d_1 = \frac{0.5C\left(1 - \frac{g}{C}\right)^2}{1 - \left[\min(1, X)\frac{g}{C}\right]}$$

Where C = is the cycle length, g/C = is the green time to cycle ratio = 0.5 (for simplicity) and X is the highest volume to capacity ratio of any turning movement or a lane group at the intersection.

The improvement in delay experienced per vehicle due to signalization is transformed into total delay in vehicle hours and thereby used for estimation of emission reductions.

Estimated delay in this methodology is assumed to be uniform delay resulting due to uniform arrival of traffic at the intersection, which is an ideal assumption. In the absence of detailed turning movement data and proposed signal timing and phasing details, green time to cycle ratio is assumed to be 0.5. It should be recognized that the mid-block capacity of a street is different from the capacity at the intersection due to turning traffic and effects of signal controls.

Project Type #2- New Turn Phase

Intersection delay can be reduced by enabling a specific turn or movement at the intersection that was non-existent or permissive before into a protected turn by providing a new phase, or by including the movement in an existing phase by changing the time allocated to the phase. If the movement is not allowed at the intersection in the existing set-up, the existing delay is assumed to reflect a level of service F or more, which translates into a delay of 80 seconds or more. By providing protected phase to this movement, we are not only changing the signal timing plan, but also potentially adding to the cycle length. Because the delay at the intersection will be reduced for this movement, due to the provision of a green time to serve this movement, delay can be calculated based on the new cycle time and the effective green time for that movement.

The same formula presented in Project Type 1 is used to calculate before and after intersection delay. This methodology relies on assuming several constants for estimation of delay at the intersection for the turning lane group. Saturation flow rate is adjusted to area type and based on the type of turn. Saturation flow rate in CBDs and urban areas is assumed to be 1,700 veh/hr/lane[3]. Further, this saturation rate needs to be adjusted for the type of turn, which is lower for right and left turns compared to the through movement. For right turns, the adjustment factor is 0.85 and for left turns, it is 0.95. The default v/c ratio for the turning movement is 0.9.[4]

Project Type #3– – Improved Intersection Capacity

Physical changes to the intersection for increasing capacity or geometric design, including provision of new through or turn lanes can reduce delay-related emissions at congested intersections under certain conditions. These changes to capacity result in an easing of capacity restrictions due to changes caused by the improvement. Volume is considered constant for practical purposes, since it is hard to estimate the quantity of traffic that is re-routed from other facilities due to improvement in delay at the intersection. Given the added capacity and geometric redesign resulting in delay reduction, a comparative analysis of intersection configuration before and after the improvement can be conducted to estimate the reduction in greenhouse gas emissions due to physical intersection design changes.

The same formula presented in Project Type 1 is used to calculate before and after intersection delay. Effective green to cycle ratio is assumed to be 0.5 for simplification in absence of turning movement and signal timing data to calculate it. Traffic is assumed to arrive in a uniform fashion at the intersection and improvement in uniform delay is estimated for calculating reductions in total greenhouse gas emissions as a result of improved geometric design and approach changes.

2.4 SYSTEM OPERATIONS

Overview and Project Types

Projects that can be evaluated using this methodology include corridor signalization and synchronization improvements and intelligent transportation systems (ITS)/Advanced Traffic Management System (ATMS) implementation. Travel timesavings at each intersection along the corridor are calculated and aggregated by applying a delay reduction factor.

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[3] Highway Capacity Manual (HCM 2000), Chapter 16-11, Adjustments for Saturation Flow Rate Chapter.

[4] HCM 2000, Chapter 16-99, Signalized Intersections, Design Strategies for Signal Timing Plan Design for Pre-timed Control.

Methodology Limitations

This method specifically evaluates arterial management strategies, such as corridor signalization, and cannot estimate systemwide or areawide improvements. However, areawide improvements can be estimated by testing individual corridors separately and summing their unique impacts. The length of the corridors and the signals being improved for synchronization should be reasonably spaced to achieve a meaningful reduction in travel savings. For example, travel time savings will be minimal for two signals spaced a mile apart compared to seven signals in a one-mile corridor.

User-Defined Inputs

The methodology requires the set of project-specific, user-defined inputs presented in Table 2.5.

Table 2.5 System Operations Project User-Defined Inputs

User-Defined Input	Default Values	Input Guidance
Length of the signalized corridor (miles)		• Enter length of corridor targeted for signal synchronization
Existing number of signalized intersections		• Enter number of signalized intersections in the corridor
Existing number of lanes		• Enter number of through lanes that serve the highest directional flow of the peak-hour traffic in the corridor • Intersection turn pockets are represented by ½ lane
Peak-hour traffic volume		• Enter highest one-hour directional volume of the day in the corridor for the highest volume segment in the corridor
Existing peak-hour travel time (minutes)		• Enter time it currently takes for a vehicle to travel the length of the corridor during the peak hour in the peak direction
Existing average cycle length (seconds)		• Enter average cycle length of all the signalized intersections in the corridor

Methodology

This methodology uses California DOT's (Caltrans) Traffic Light Synchronization Program (TLSP)[5] evaluation algorithms to calculate delay at each intersection along a defined corridor. The TLSP offers an established method of calculating various benefits of corridor traffic signal synchronization in California, and is consistent with the evaluation and calculation of fuel savings from signal synchronization projects in the State of California. Travel timesavings due to the synchronization are estimated by calculating average delay at each intersection in the corridor. The travel timesavings formula is based on the Highway Capacity Manual (HCM) equation for delay (Equation 16-11 Chapter 16). When signals are synchronized, it is assumed that delay is reduced by a factor of 0.55.[6]

$$d_1 = \frac{0.5C\left(1-\frac{g}{C}\right)^2}{1-\left[\min(1,X)\frac{g}{C}\right]}$$

Where:

C = Cycle length; and

g/C = Green time to cycle ratio.[7]

The travel timesaving is the difference in seconds per vehicle per signal. It is multiplied by the number of signals and divided by 60 to return the benefit in minutes per vehicle for the total length of the arterial. Finally, the approach multiplies this by the volume to estimate total savings in minutes.

2.5 GRADE SEPARATION

Overview and Project Types

This approach evaluates projects that improve the roadway capacity and safety of current at-grade railroad crossings. Potential improvements include grade

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[5] Caltrans (2008), *Traffic Light Synchronization Program (TLSP) Evaluation and Scoring Methodology*, California Department of Transportation, available on-line at: http://www.catc.ca.gov/programs/tlsp.htm.

[6] HCM (2000), *Highway Capacity Manual*, Transportation Research Board (TRB), Exhibit 16-12.

[7] To avoid users having to enter time-to-cycle ratios for each intersection, g/C is assumed to be 0.5 for the corridor. This is a recommended practice per HCM (2000).

separation of at-grade railroad crossings, which reduces delay caused by at-grade railroad facility conflicts.

This method is applicable for projects that facilitate uninterrupted movement for vehicles along a roadway and reduce delay at the crossing. Average gate down time is used as a proxy for intersection delay prior to the grade separation improvement. Gate down time varies between freight rail and passenger rail, and should be adjusted in accordance with the type and number of trains operating along the rail corridor.

Methodology Limitations

This approach should only be used to analyze projects that remove at-grade crossings of active rail corridors. Installing a grade-separated interchange at an existing at-grade intersection is not accommodated through this project approach. Improvements to at-grade rail crossings that do not include a full grade separation can be analyzed as long as future average crossing speed can be estimated, and the total daily delay resulting from queues when gates are down does not change.

User-Defined Inputs

The methodology requires the set of project-specific, user-defined inputs presented in Table 2.6.

Table 2.6 Grade Separation Project User-Defined Inputs

User-Defined Input	Default Values	Input Guidance
Daily number of trains using rail corridor		• Enter average number of weekday trains passing through the at-grade crossing
Average gate down time for each train (minutes)		• Enter average length of time during which the gate at the crossing remains down for each train
Roadway average daily traffic		• Enter total daily weekday traffic on the highway facility
Average vehicle railroad crossing speed (mph)	25 mph	• Enter average speed of vehicles negotiating the crossing when gate is not down • According to the California Department of Motor Vehicle (DMV), speed limits are to be 15 mph within 100 feet of a railroad crossing without gates; it is assumed that most urban locations have gates, and hence have a default crossing speed of 25 mph
Improved roadway posted speed limit (mph)		• Enter improved speed due to the construction of a grade-separation or other alternative that eliminates at-grade conflicts

Methodology

The duration of conflict of movement between roadway and railroad modes can be calculated by assuming an average gate down time for trains passing through the crossing, which is a proxy for existing intersection delay. Once there is a grade separation, the intersection delay is avoided completely, resulting in fuel savings, and thereby emission reductions.[8]

This methodology assumes that railroads are afforded preference of movement (right-of-way) at the intersection, thereby eliminating any delays to the rail services due to roadway traffic (Extreme circumstances like passage of emergency vehicles is not considered to occur frequently enough to affect rail services substantially.). Three types of vehicle delays result from an at-grade crossing: 1) stopping, 2) deceleration, and 3) queuing. Since stopping delay accounts for the vast majority of delay experienced by vehicles at an at-grade crossing, it is considered a reasonable and conservative proxy for total at-grade delay.

Because data on the length and type of trains passing through the grade crossing may be difficult for most users to specify accurately, an average gate down time is used to approximate vehicle delay. Gate down time and total vehicles delayed are estimated as follows:

Gate Down Time = Length of the Train/Train Speed

Total Vehicles Delayed (Daily) = Total Gate Down Time (Daily hrs)/24 x Annual Average Daily Traffic (AADT)

The approach assumes that the total vehicular traffic impacted by delay caused by gate down time is equal to the total daily share of gate down time.

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[8] ICC (2002-2003), *Motorist Delay at Public Highway– – Rail Grade Crossings in Northeastern Illinois*, Research and Analysis Section Transportation Division, Illinois Commerce Commission, Working Paper.

Table 2.7 Bike/Pedestrian Project User-Defined Inputs

User-Defined Input	Default Values	Input Guidance
ADT on the parallel arterial		• Enter average weekday passenger vehicle traffic on nearest parallel roadway
Length of project (miles)		• Enter total length of the bike/pedestrian project
Within 2 miles of a university or college (Y/N)?		• Select "Y" if any segment of project is within 2 miles of a university or college
Average length of bicycle trips (miles)	1.8	• Enter estimated average length of bicycle trips in the area; leave blank if a pedestrian project only • Default value (1.8 mi) is based on National Household Travel Survey (NHTS) statistics, excluding purely recreational trips.
Average length of pedestrian trips (miles)	0.5	• Enter estimated average length of pedestrian trips in the area; leave blank if bike project only • Default value (0.5 mi) is based on NHTS statistics, excluding purely recreational trips
Number of activity centers within ½ mile and ¼ mile of project		• Select the number of activity centers within ½ mile (bike) and ¼ mile (pedestrian) of the project • Activity center examples include banks, churches, hospitals, park-and-ride, office parks, library, shopping, and schools; credit is only given for 3 or more centers

Methodology

The bike project approach is consistent with *Methods to Find the Cost-Effectiveness of Funding Air Quality Projects*, a handbook prepared by the CARB in 2005. The CARB handbook describes how to evaluate Motor Vehicle Registration Fee Projects and Congestion Mitigation and Air Quality Improvement (CMAQ) projects, and is the basis for determining the amount of GHG reductions from bicycle facility projects.

The 2009 report *Methodologies for Evaluating Congestion Mitigation and Air Quality Improvement Projects*, developed for the Maricopa Association of Governments (MAG), is the basis for determining GHG reductions resulting from auto trips replaced by pedestrian trips. The MAG document adapted the methodology for calculating the impact of pedestrian improvements from the 2005 CARB handbook.

The approaches for bike and pedestrian projects are consistent. Within the general CARB approach, two primary factors drive the calculation of reduced auto trips: 1) the number of activity centers adjacent to the project, and 2) the project location with respect to a nearby university or college.[9] These factors are presented in Appendix C.

The number of activity centers within one-quarter mile of a pedestrian project and one-half mile of a bike project feed into a lookup table of factors generating percent auto trip reductions. The university/college location factor increases average trip lengths on the assumption that willingness to bike or walk, and the average distances for these trips are greater for college students.

Auto trip reductions are translated into VMT based on average bike and walk trip lengths. These average trip lengths default to 2001 National Household Travel Survey (NHTS) data, but the user interface allows users to override these figures with local-specific data.

Calculations for auto trips reduced as a result of increased bike and pedestrian trips generated by the project are listed below. Trips are then equated to VMT savings based on average bike and walk trip lengths. The VMT reductions are calculated separately for bike and pedestrian on a daily scale, then summed together and annualized (assumes a factor of 250 days, since commute benefits are assumed only to accrue during workdays). The GHG emissions calculation approach is included in Section 4.0.

$$\text{Daily auto trips reduced}_{\text{(bike)}} = AWT * 0.091 * (A_{\text{½ mile}} + C)$$

$$\text{Daily auto trips reduced}_{\text{(walk)}} = AWT * 0.091 * (A_{\text{¼ mile}} + C)$$

Where:

AWT = Average weekday traffic on the adjacent or nearest parallel arterial.

0.91 = Factor to convert average weekday traffic to AADT.

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[9] Per CARB documentation, adjustment factors were derived from a limited set of bicycle commute mode split data for cities and university towns in the southern and western United States (Source: U.S. DOT (1992), *National Bicycling And Walking Study– –Transportation Choices for a Changing America*). This data was then averaged and multiplied by 0.7 to estimate potential auto travel diverted to bikes. On average, about 70 percent of all person trips are taken by auto driving (Source: Caltrans (2002), *2000-2001 California Statewide Travel Survey*), and it is these trips that can be considered as possible auto trips reduced. Finally, this number was multiplied by 0.65 to estimate the growth in bicycle trips from construction of the bike facility. Sixty-five percent represent the average growth in bike trips from a new bike facility, as observed in before and after data for bike projects (Source: U.S. DOT (1994), *A Compendium of Available Bicycle and Pedestrian Trip Generation Data in the United States*). Benefits are scaled to reflect differences in project structure, length, traffic intensity, community size, and proximity of activity centers. The scale has been adapted from a method developed by Dave Burch of the Bay Area Air Quality Management District (BAAQMD).

A = Adjustment factor for ADT (auto trips replaced by bike or pedestrian trips). The adjustment factor is based on a lookup table of project length and AADT.

C = Credit for number of activity centers within one-quarter mile of the pedestrian project and one-half mile of the bike project.

2.6 BIKE/PEDESTRIAN AND TRANSIT

Overview and Project Types

This approach evaluates all bike and pedestrian infrastructure improvements that provide increased nonmotorized accessibility to transit. Projects can be evaluated individually for bike or pedestrian facilities, or combined. The approach and rules for inputs are similar to those used in the bike/pedestrian project-type methodology, but also include additional factors to estimate the effect of the interaction of nonmotorized infrastructure improvements with existing transit facilities.

Pedestrian and bicycle facilities can reduce GHG emissions when auto trips are replaced by walking and biking to transit stations. The methodology estimates the annual number of vehicle trips reduced, and the annual auto VMT reduced to approximate the GHG reduction associated with pedestrian and bike improvements at and around transit stations.

Methodology Limitations

The approach does not completely account for all elements of pedestrian bridges or multiuse facilities/greenways in exclusive ROW; however, these can be tested with careful consideration of inputs. In these cases, the total travel demand between the facility start point and end point, or an estimate of total walk or bike access trips to the transit stop or station can be entered in lieu of ADT.

The approach does not test potential mode shifts to nonmotorized and transit modes as a result of complete street elements (e.g., benches, lighting, improved buffers); traffic-calming strategies; transit station design elements, such as a bike station; employer-based strategies (e.g., bike lockers, showers); or improved transit amenities.

User-Defined Inputs

The methodology requires the set of project-specific, user-defined inputs presented in Table 2.8.

Table 2.8 Bike/Pedestrian and Transit Project User-Defined Inputs

User-Defined Input	Default Values	Input Guidance
Project Type		• Select from bike, pedestrian, or bike + pedestrian.
ADT on the parallel arterial		• Enter average weekday passenger vehicle traffic on nearest parallel roadway.
Length of project (miles)		• Enter total length of the bike/pedestrian project.
Average length of bicycle trips (miles)	1.8	• Enter estimated average length of bicycle trips in the area; leave blank if a pedestrian project only. • Default value (1.8 mi) is based on 2001 NHTS statistics, excluding purely recreational trips.
Average length of pedestrian trips (miles)	0.5	• Enter estimated average length of pedestrian trips in the area; leave blank if bike project only. • Default value (0.5 mi) is based on 2001 NHTS statistics, excluding purely recreational trips
Average length of transit trips (miles)	5.2	• Enter estimated average length of transit trips in the area. • Default value based on the American Public Transportation Association (APTA) 2009 Factbook,[10] Table 7 (Bus = 3.9 mi; Commuter Rail = 24.3 mi; Heavy Rail = 4.7 mi; Average = 5.2 mi).
Number of activity centers within ½ mile of project		• Select appropriate number of activity centers. • Activity center examples include banks, churches, hospitals, park-and-ride, office parks, library, shopping, and schools.
Within 2 miles of a university or college (Y/N)?		• Select "Y" if any segment of project is within 2 miles of a university or college.
Area type		• Select from CBD, Urban, Suburban, Mountain, and Rural area types. • Definitions based on traffic analysis zone attributes and inherited from the SCAG travel demand model (see Appendix A).
Does project provide direct access to transit?		• Answer "Y" if any segment of project provides direct access to transit (station or bus stop).
Existing daily transit boardings		• Enter estimated total weekday boardings for all transit access points along project corridor.
Provides access to fixed guideway transit?		• Select "Y" if the segment provides direct access to fixed guideway transit.

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[10] APTA (2009), *Public Transportation Factbook, 60th Edition,* American Public Transportation Association, accessed at http://www.apta.com/gap/policyresearch/Documents/APTA_2009_Fact_Book.pdf.

Methodology

The bike and pedestrian project approach follows the same procedures outlined in Section 2.6. The additional transit access element within this project approach is addressed through a lookup table quantifying the increase in transit trips, based on type of access and area type (two percent for improved access to bus; four percent for improved access to fixed guideway).

The source for increases in transit trips is the Transit Cooperative Research Program (TCRP) Report 95, *Traveler Response to Transportation System Changes, Chapter 17 – Transit-Oriented Development (TOD)*, which summarizes travel mode shifts of residents upon relocation into TODs. The TCRP report specifically references California results based upon a 2003 study by Lund, Cervero, and Willson.[11] The shift to transit was larger for residents along the Bay Area Rapid Transit District (BART) heavy-rail system (4.2 percent) than for TOD survey respondents statewide (1.8 percent). These results indicated a reasonable estimate for percent increases as a result of improved accessibility: two percent for bus trips and four percent for fixed guideway trips. Results from the *TCRP Report 95* sources are assumed to approximate responses in high-density areas. Increase percentages in suburban, mountain, and rural areas are based on VMT per capita relationships by population density from the 2001 NHTS (see Tables 2.9 and 2.10).

Table 2.9 Increase in Transit Trips by Area Type and Transit Mode

Area Type	Bus	Fixed Guideway
CBD/Core	2.0%	4.0%
Urban	2.0%	4.0%
Suburban	1.6%	3.2%
Mountain	1.4%	2.8%
Rural	1.4%	2.8%

Source: NHTS (2001).

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[11] H. Lund, R. Cervero, and R. Willson (2003), *Travel Characteristics of Transit-Oriented Development in California*, accessed at: http://www.csupomona.edu/~rwwillson/tod/Pictures/TOD2.pdf.

Table 2.10 VMT per Capita by Area Type

Area Type	Population Density People per Square Mile (ppsm)	Annual VMT Per Capita
Mountain/Rural	0– – 499	11,818
Suburban	500 -1,999	10,435
Urban	2,000– – 3,999	9,678
Urban	4,000– – 9,999	8,285
CBD/Core	10,000+	4,639

Source: 2001 NHTS.

Auto trips reduced by bike, walk, and transit modes are translated into VMT based on average bike, walk, and transit trip lengths. The methodology uses default average trip lengths based on the NHTS and APTA *2009 Factbook* data, but can be replaced with user-defined, local-specific data.

For a description of the methodology for calculating reduced auto trips resulting from the project, see Section 2.6.4. The calculation for transit trips is detailed below. Trip reductions are equated to VMT savings based on average bike, walk, and transit trip lengths. VMT reductions are calculated separately for all modes on a daily scale, and then summed together and annualized (assuming a factor of 250 days). For the GHG emissions calculation approach, see Section 4.0.

$$\text{Daily auto trips reduced}_{\text{(transit)}} = B_{\text{(project corridor)}} * I_{\text{(area type \& mode)}}$$

B = Daily transit boarding for all transit access points along bike/ pedestrian project corridor; and

I = Percent increase in transit trips as presented in Table 2.9.

2.7 TRANSIT EXPANSION

Overview and Project Types

Transit expansion projects can cause shifts from auto travel, resulting in reductions in VMT and thus GHG emissions. The methodology assumes that, per passenger mile, all modes of transit, including buses, emit less CO_2 than an average occupancy light-duty vehicle trip.

This methodology estimates the emission reduction benefits of transit amenities, such as real-time transit arrival information or decreased out-of-vehicle travel times due to increased frequency of service (or reducing headways) and fleet expansions.

Methodology Limitations

This method is not applicable to new transit routes in areas without existing transit services. The evaluation design is tailored to "typical" CMF-eligible projects (e.g., purchasing new buses, headways, stop amenities, traveler info). Improvements such as service extensions; new corridors; new stations; general enhancement of transit amenities (stops, sidewalks, benches); transit signal priority; queue jumper lanes; or bus rapid transit (BRT) are beyond the scope of this analysis.

User-Defined Inputs

The methodology requires the set of project-specific, user-defined inputs presented in Table 2.11.

Table 2.11 Transit Expansion Project User-Defined Inputs

User-Defined Input	Default Values	Input Guidance
Average peak-period headway before improvements (mins)		• Enter average peak-period headway (minutes) before the project (2010)
Average peak-period headway after improvements (mins)		• Enter average peak-period headway (minutes) after the project (2020)
Does project include real-time arrival information?		• Select "Y" if project involves real-time arrival information
Existing (2010) project corridor transit travel time (mins)		• Enter average time it takes transit to travel the affected corridor (average can be for one route or across multiple routes)
Average peak-period transit ridership (2010) affected by improvements		• Enter average peak-period transit ridership affected by improvements (2010)

Methodology

The approach calculates the increase in transit ridership resulting from a change in headways using elasticities reported in the TCRP Report 95.[12] The methodology applies an average headway elasticity of +0.5. In other words, for each 1-percent decrease in headways, a corresponding 0.5-percent increase in

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[12] TCRP 95c9 (2004), *TCRP Report 95, Chapter 9– – Transit Scheduling and Frequency*, Transportation Research Board, on-line at: http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_95c9.pdf.

ridership occurs. This elasticity is derived from an average effect observed on multiple bus transit systems in urban areas across the U.S. CS performed a validation using coefficients in SCAG's mode choice model, and arrived at a comparable elasticity for changes in headways in Southern California.

The TCRP Report 95 references case studies for Santa Clarita Transit in the mid-1990s and Santa Monica Municipal Bus Lines in 1998 that suggest the region-specific headway elasticity may be higher– – from +0.8 to +1.1. However, the current calculation framework maintains the more conservative +0.5 elasticity assumption.

The equation to calculate the change in ridership and resulting decrease in weekday light-duty VMT is as follows:

$$VMT = \frac{(\Delta H \times e_h \times R)}{AVO} \times TL$$

Where:

VMT = Reduction in daily light-duty VMT;

ΔH = Percent change in headways due to improvement;

e_h = Headway elasticity (-0.5);

R = Existing ridership impacted improvement;

AVO = Average passenger vehicle occupancy; and

TL = Average passenger vehicle trip length.

The methodology also accounts for the impact of real-time transit arrival information, which is based on an average travel time reduction as a result of real-time transit information. The 1995 NHTS indicated that transit wait times represent 22 percent of total transit trip time (or 10 minutes) on average (This was also validated through evaluation of the 2001 NHTS.).[13] The methodology assumes that the presence of real-time transit arrival information allows users to reduce average wait times by approximately 50 percent, resulting in a 10-percent reduction of overall travel time.

$$VMT = \frac{(\Delta T \times e_t \times R)}{AVO} \times TL$$

Where:

VMT = Reduction in daily light-duty VMT;

ΔT = Percent change in travel time due to real-time arrival info (10 percent);

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[13] CUTR (1998), Public Transit in America: Findings from the 1995 Nationwide Personal Transportation Survey, Center for Urban Transportation Research, Table 4-13.

et = Travel time elasticity (+0.23);[14]

R = Existing ridership impacted improvement;

AVO = Average passenger vehicle occupancy; and

TL = Average passenger vehicle trip length

The reduction in GHG caused by shorter headways is offset somewhat by the addition of transit revenue miles that generate CO_2 emissions. The increase in total corridor transit revenue miles is estimated via the change in total number of daily buses multiplied by transit corridor length.

2.8 PARK-AND-RIDE

Overview and Project Types

Increasing parking capacity at transit stations reduces emissions by encouraging single-occupant vehicle drivers to shift to transit for a proportion of their commute trip.

This method is applicable for new or existing parking lots providing park-and-ride access to transit. The projects can include both expansions of existing parking facilities adjacent to transit. The user-defined type of transit station (urban rail, commuter rail, BRT/express bus, or transit center) determines the share of additional parking lot users that are new transit riders. This factor is combined with a parking lot utilization factor to estimate reduced vehicle trips as a result of the parking expansion.

Methodology Limitations

This methodology is not designed to estimate the impact of a new parking facility associated with a new transit station. The station must be existing with some level of existing parking available, but any type of existing parking (public, private, or shared) or type of transit station can be accommodated.

User-Defined Inputs

The methodology requires the set of project-specific, user-defined inputs presented in Table 2.12.

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[14] VTPI (2010), *Transportation Elasticities: How Prices and Other Factors Affect Travel Behavior.* Victoria Transport Policy Institute, May 3, 2010.

Table 2.12 Park-and-Ride Project User-Defined Inputs

User-Defined Input	Default Values	Input Guidance
Transit station type		• Select from urban rail, commuter rail, BRT/express bus, transit center, or other.
Additional parking added by 2020		• Enter number of new parking spaces (by expansion of an existing lot or a new lot).
Average auto trip length (miles)	15	• Enter average commute distance traveled by autos in the area. • 15 miles is the default option, based on 2009 NHTS data for the Los Angeles-Riverside-Orange County MSA.[15]
Average weekday parking lot utilization	95%	• Enter post-parking expansion expected average weekday utilization expected • Default value, 95% parking occupancy, is the assumed utilization in MTA's Gold Line Draft Environmental Impact Statement (DEIS)[16]; • Other input guidance by transit station type: 77% for Metrolink (the midpoint of the 70-85% range for commuter rail reported in TCRP 95, Ch.3), 65% for BRT/Express Bus; and 50-60% for urban bus systems/shared use facilities.[17]
Average auto access trip length (miles)	5	• Enter the average distance traveled by vehicles accessing the park-and-ride lot. • 5 miles is the default option. As a reference, per TCRP Report 95 (2004), 80% of trips to a park-and-ride facility travel less than 10 miles. Given the density of transit service in LA County, an average drive to park-and ride of less than 10 miles is reasonable for this application.
Parking lot usage	Weekdays	• Select from weekdays (250 days per year) and everyday (365 days per year)

Methodology

The approach calculates the CO_2 emissions reductions from added parking capacity at transit stations as a result of new transit riders shifting from the

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[15] NHTS (2009), *National Household Travel* Survey, data available at: http://nhts.ornl.gov/tools.shtml,

[16] MTA (2004), *Gold Line Phase II– – Pasadena to Montclair– – Foothill Extension DEIS/DEIR*, Los Angeles County Metropolitan Transportation Authority, pp. 3-15-87.

[17] TCRP 95c3 (2004), *TCRP 95, Chapter 3– – Park and Ride/Pool*, Transportation Research Board, http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_95c9.pdf.

private vehicle mode. The calculation of the VMT reduction is tied to a combination of user-defined inputs, as presented in Table 2.12. In addition, the percentage of new transit riders utilizing park-and-ride lots is assumed to be 37 percent, pursuant to data collected for the Metro Gold Line Foothill Extension environmental documents.[18]

The calculated VMT reduction is only applied to the portion of the trip length that shifts from auto to transit. Default average auto commute trip lengths and auto access to park-and-ride trip lengths are assumed to be 15 and 5 miles, respectively (see Table 2.12 for references). However, users may substitute unique corridor- or subregion-specific average auto trip length and auto access to parking trip lengths.

The volume of new transit riders utilizing the expanded park-and-ride lot capacity is estimated by multiplying the new parking spaces by the parking lot utilization, and by the percent of new riders using the park-and-ride lots (37 percent).[19] This new rider estimate is multiplied by the average round trip distance, excluding auto access, to obtain a daily VMT reduction for the project. The daily VMT reduction is calculated as follows:

$$VMT = \frac{(TL_1 - TL_2)}{2} \times (P \times U * NR_m)$$

Where:

VMT = Reduction in daily light-duty VMT;

TL_1 = Average auto trip length;

TL_2 = Average auto access to PNR trip length;

P = Total added parking spaces;

U = Average parking lot utilization; and

NR_m = Percentage of new transit riders using park and ride lot (37 percent).

2.9 MANAGED LANES

Overview and Project Types

The emissions reduction for transit managed lanes projects is calculated based on the benefit of: 1) decreased travel time on ridership, and 2) increased bus transit speed on GHG emissions per mile.

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[18] FTA (2003), *Metro Gold Line East Side Extension, Pending Full-Funding Grant Agreement*, Federal Transit Administration. www.fta.dot.gov/documents/LA_Metro1AA.doc.

[19] Per TCRP 95c3 (2004), the percent of new riders using park-and-ride lots varies from 20 to 75 percent nationwide. Per FTA (2003), 37 percent of ridership are new riders.

The El Monte busway project assumes new ramp access to an existing managed lane facility. This project approach evaluates the benefit of switching a portion of an existing bus transit corridor operating in general purpose lane traffic to a managed lane as a result of new ramp access points.

Methodology Limitations

The methodology does not consider any inputs or emission impacts regarding change in corridor transit service (headways or route alignment), any mode shifts from single-occupancy vehicle (SOV) to HOV as a result of new managed lane capacity, or a general reduction in corridor delay resulting from overall improved flow. While there are expected GHG emission impacts resulting from these outcomes of managed lane projects, at this point, the benefit to existing transit is the only outcome considered per the currently proposed list of CMF projects.

User-Defined Inputs

The methodology requires the set of project-specific, user-defined inputs presented in Table 2.13.

Methodology

The user-defined inputs presented in Table 2.13 describe characteristics of the managed lane (restrictions, AADT, and number of lanes) and the corridor transit service (travel time, total length, length on managed lane, peak and off-peak number of buses, and existing daily ridership).

These inputs are combined with default transit-related factors, such as the elasticity of transit ridership with respect to travel time. Managed lane capacity and free-flow speed assumptions come from the same speed and capacity lookup table used in the roadway capacity methodology.

Table 2.13 Managed Lane Project User-Defined Inputs

User-Defined Input	Default Values	Input Guidance
Managed lane restrictions		- Select the appropriate managed lane restriction: 1) bus only, 2) HOV, or 3) HOV + high-occupancy toll (HOT)
Managed lane annual average daily traffic		- Enter the existing average daily traffic on the managed lane facility. - If restriction = 1, AADT = total daily buses; if 2, AADT = buses + HOV; if 3, AADT = buses + HOV + tolled SOV
Managed lane # of lanes (one-way)		- Enter number of managed lanes in a single direction (peak direction, if reversible lanes are in place)
Corridor total average travel time (min) (existing)		- Existing average travel time for the transit corridor (route start point to end point)
Total transit corridor length (mi)		- Enter transit corridor length (route start point to end point)
Corridor length on managed lane (mi)		- Enter total mileage of transit corridor proposed for operation on the managed lane
Daily # of peak buses (6:00-9:00 a.m., 3:00-:00 p.m.)		- Enter total number of peak-period buses
Daily # of off-peak buses		- Enter total number of off-peak-period buses
Daily corridor transit ridership affected by improvements		- Enter existing transit ridership in the affected transit corridor

Existing average speed on the transit corridor is calculated based on user-defined corridor length and travel time. Managed lane average peak speeds are estimated based on MTA model speed-volume curve equations, while off-peak speeds are assumed to represent free-flow conditions. Calculated speeds are reduced by 10 percent to reflect slightly slower transit vehicle operating speeds.

$$S_m = S0/(1+1.5X^{\wedge}6)$$

Where:

S_m = Managed lane average peak transit speed

$S0$ = Managed lane free-flow speed (70 mph) * 0.9 (adjustment for transit vehicles); and

X = Peak-period volume/capacity.

Based on the changes in average speed and corridor distance on and off the managed lanes, improved total peak and off-peak travel times are calculated. The difference in travel time is applied to the transit ridership with respect to travel time elasticity (+0.23) to obtain an estimate of the increase in transit trips. Transit trips are converted to VMT savings based on average trip lengths and average vehicle occupancy.

$$VMT = \frac{(\Delta T \times e_t \times R)}{AVO} \times TL$$

Where:

VMT = Reduction in daily light-duty VMT;

ΔT = Percent change in travel time resulting from change in route alignment to managed lane;

e_t = Travel time elasticity (+0.23);[20]

R = Existing ridership impacted improvement;

AVO = Average passenger vehicle occupancy; and

TL = Average passenger vehicle trip length.

In addition, the change in average transit corridor travel speed is input into CO_2 emission factor lookup tables to estimate emission reductions resulting from more efficient travel conditions.

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[20] VTPI (2010).

3.0 Other Project Types

Two project types entered in the July 2010 CMF project list were considered for inclusion within the tool, but were removed from the tool development process due to insignificant GHG reduction potential and questionable adherence to AB 1600 nexus requirements.

3.1 CORRIDOR IMPROVEMENT/STREETSCAPE

These projects involve the installation of medians, new landscaping, street lighting, signage or pedestrian amenities (i.e., benches, trash cans). It is not clear how median installation would positively affect speed or travel time in a way that substantially impacts GHG emissions. Conventionally, installation of a median reduces speeds and reduces truck traffic in urban settings– – commonly due to the difficulty in navigating around the barriers. While the other elements within this project category may lead to increased walking, biking, or transit research, the literature is not conclusive on the level of impact. Benefits of improved bike, pedestrian, and transit infrastructure are included in other project types within the tool.

3.2 ROADWAY UPGRADE

A national comparison of speed study results for individual resurfacing sites found that the differences in mean speed before and after resurfacing ranged from an increase of 7 mph to a decrease of 4 mph, with an average of 1 mph increase. The differences in 85th percentile speed ranged from an increase of 6 mph to a decrease of 4 mph; also with an average difference of 1 mph.[21] These findings suggest negligible potential for reducing regional GHG emissions through resurfacing.

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[21] NCHRP (2003), *NCHRP Report 486: Systemwide Impact of Safety and Traffic Operations – Design Decisions for 3R Projects*, National Cooperative Highway Research Program.

4.0 GHG Emission Calculations

4.1 EMFAC CO_2 EMISSION FACTOR LOOKUP TABLES

The CARB's EMFAC model was used to calculate CO_2 emission factors by speed and vehicle type. EMFAC is the official emissions model for California, and is currently being used by SCAG for SB 375 analysis. Since EMFAC does not consider the recently implemented Pavley I clean car standards or the Low Carbon Fuel Standard (LCFS) in California, adjustments were made after the EMFAC runs were completed.[22] CARB has created a post-processor for EMFAC that adjusts for these new standards, but it does not accept emission factors by speed. Therefore, the adjustments were made manually in an Excel sheet.

The following steps summarize the assumptions supporting the EMFAC runs and the outputs post-processed to provide CO_2 emission factors by speed and vehicle type:

1. Run EMFAC using the following parameters:
    a. Los Angeles County;
    b. Calculation Method: Use Average;
    c. Calendar Years: 2010, 2020, and 2030;
    d. All model years;
    e. All vehicle classes;
    f. Default I/M program schedule;
    g. Burden Inventory Output;
    h. Detailed Planning Inventories (CSV);
    i. Provide detail for model years, tech groups, and speed; and
    j. Speed Categories: 5 mph.
2. Summarize CO_2 running emissions inventory by calendar year, vehicle type, tech group (selecting only total for each speed category), and model year.
3. Summarize VMT by calendar year, vehicle type, tech group (selecting only total for each speed category), and model year.

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[22] The regional per capita emissions reduction targets set by CARB do not include emissions reductions resulting from Pavley I or LCFS.

4. Divide each CO_2 inventory number by each VMT number to obtain CO_2 emission factors. Multiply by 907,184.74 grams per ton to convert from tons per mile to grams per mile.
5. Apply Pavley reduction factors to appropriate vehicle types and model years, as specified in CARB's User's Guide for the Pavley I + LCFS Post-Processor.[23]
6. Calculate composite emission factor for all model years by using a VMT-weighted average.
7. Apply an adjustment factor for the LCFS to the composite emission factor using the reduction factors found in CARB's User's Guide for the Pavley I + LCFS Post-Processor.[24]
8. Final CO_2 emission factors are provided in grams per mile by speed and vehicle type.

Since EMFAC does not provide idling emission rates in grams per hour, these were approximated by using emission rates for 3 mph. These were calculated in EMFAC using the same method, as described above; however, at the end the gram per mile emission rates are multiplied by 3 miles per hour to convert to grams per hour.

All metric units were subsequently converted to pounds (lbs).

Table 4.1 presents the lookup tables used in the emissions calculator tool. Results by vehicle type are aggregated into three primary vehicle types for the emissions calculation lookups by project type. The aggregation of emissions factors are based on a weighting by VMT by speed by vehicle type. The aggregation process by vehicle type combines the following vehicle types:

- Light-duty passenger cars: LDA, LDT1, LDT2, and MCY; and
- All trucks: HHD, LHD1, LHD2, MDV, and MHD.

The aggregation process works the same for 2010, 2020, and 2030. Ultimately, the 2020 emissions factors are applied in the emission reduction calculations in the tool. The 2020 emission factors are presented in Table 4.1 by 5 mpg speed increments (the emission reduction calculations use each 1 mph increments).

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[23] CARB (2010), *Pavley I + Low Carbon Fuel Standard Postprocessor, Version 1.0 User's Guide*, California Air Resources Board, http://www.arb.ca.gov/cc/sb375/tools/pavleylcfs-userguide.pdf, Table 1.

[24] Ibid., Table 2.

Table 4.1 2020 CO_2 Emission Factors by Vehicle Type and Speed

	Vehicle Type		
	Light-Duty	Truck	Urban Bus
Speed	CO_2 grams/mile		
Idle (grams/hour)	2,724.96	5,197.15	7,081.33
5 mph	908.32	1,732.38	2,360.44
10 mph	675.38	1,383.41	2,217.43
15 mph	520.03	1,092.16	2,024.59
20 mph	415.75	896.14	1,908.85
25 mph	345.56	785.96	1,837.53
30 mph	297.38	718.25	1,793.02
35 mph	265.70	676.46	1,765.58
40 mph	247.89	680.79	1,749.82
45 mph	239.65	691.13	1,742.88
50 mph	239.63	676.64	1,743.56
55 mph	248.70	695.19	1,751.97
60 mph	266.66	744.09	1,769.58
65 mph	296.33	882.24	-
70 mph	310.31	919.65	-
Average VMT Weighted Speed	327.36	807.25	1,826.77

Note: All emission factors by speed are grams CO_2 per mile, except for idling, which is grams CO_2 per hour.

4.2 CO_2 EMISSION REDUCTION CALCULATION

Each project calculates a change in vehicle speed, delay, or VMT; and equates these results to a reduction in CO_2. Table 4.2 presents the output for each project type and a summary of the emissions calculation.

Table 4.2 CO_2 Emission Reduction Calculations by Project Type

Project Type	Project Performance Outputs	CO_2 Emissions Calculation
Roadway capacity	Change in peak-hour speed by vehicle type for project limit VMT	Emission factors (g/mi) for pre- and post-improvement speeds are multiplied by total VMT.
Interchange capacity	Change in average peak-hour speed by vehicle type for all ramp VMT, change in intersection hours of delay.	Emission factors (g/mi) for pre- and post-improvement speeds s multiplied by total VMT; and idle emission factor is multiplied by pre- and post-improvement intersection hours of delay by vehicle type.
Grade separation	Change in speed by vehicle type for project limit VMT, total reduction in delay resulting from removing queues at existing at-grade intersection.	Emission factors (g/mi) for pre- and post-improvement speeds is multiplied by total VMT; and idle emission factor is multiplied by pre- and post-improvement intersection hours of delay.
Intersection improvement	Change in average seconds of delay per vehicle by intersection approach	Idle emission factor is multiplied by pre- and post-improvement intersection hours of delay.
System operations	Change in corridor average speed resulting from decreased travel time	Emission factors (g/mi) for pre- and post-improvement speeds (average speed for entire corridor, including idling at signalized intersections) is multiplied by total VMT.
Bike/pedestrian	Reduction in VMT	Total reduction in VMT is multiplied by average VMT weighted speed light-duty vehicle emissions factor.
Bike/pedestrian and transit	Reduction in VMT	Total reduction in VMT is multiplied by average VMT weighted speed light-duty vehicle emissions factor. No additional emissions from transit are assumed (no change in service provision).
Transit expansion	Reduction in VMT	Total reduction in VMT is multiplied by average VMT weighted speed light-duty vehicle emissions factor; and additional transit revenue miles are multiplied by average urban bus VMT weighted speed emission factor.
Park-and-ride	Reduction in VMT	Total reduction in VMT is multiplied by average VMT weighted speed light-duty vehicle emissions factor. No additional emissions from transit are assumed (no change in service provision).
Managed lanes	Reduction in VMT, improvement in transit speeds	Total reduction in VMT is multiplied by average VMT weighted speed light-duty vehicle emissions factor; and emission factors (g/mi) for pre- and post-improvement urban bus speeds are multiplied by total transit miles.

5.0 Next Steps

Depending on the next steps in the evolution of the congestion mitigation fee program, there are a range of potential updates and enhancements to the web tool calculation methodologies as currently defined. The three most critical near term enhancements are:

1. **Expansion of the transit expansion project type.** The current approach is designed only to assess benefits of a combination of average corridor transit frequency adjustment or the deployment of real-time arrival information at transit stops. The scope of potential other transit improvements included within the CMF program suggests that a number of other options may be appropriate. These additional modules within the transit approach may include transit priority corridors/signal priority, new routes or circulator systems, transit vehicle replacements (i.e., diesel replaced with hybrid or other low emission technologies).
2. **Expansion of the system operations project type.** The current approach is constrained to assessing the benefits of corridor-specific signal synchronization projects. It does not represent the full scope of traditional system management projects/programs, particular corridor, subarea, or citywide ITS and ATMS applications, as currently defined in the congestion mitigation fee program list. An enhancement to this tool, or a completely new, separate approach, is a near-term priority in order to fill in this project gap.
3. **Expansion of the managed lanes project benefits calculation.** The current approach focuses exclusively on the GHG emission reductions resulting from rerouting a portion of a bus route onto an existing managed lane via construction of new access. As more information becomes available about this project type, it is possible that inclusion of an assessment of how new managed lane access points improve HOV access to new developments and results in mode shifts and potential travel timesavings should be considered. In addition, the existing tool could also be adjusted or combined with the transit tool to assess the benefits of bus-only lanes or BRT on major arterials.

In addition, the methodologies as currently constructed can report other project-related outputs, such as reduction in VMT and reduction in delay or vehicle hours of travel. These outputs could be reported through the web tool interface; or serve as the starting point for other critical project calculations, such as project-level cost-benefit assessments and reductions in criteria pollutant emissions.

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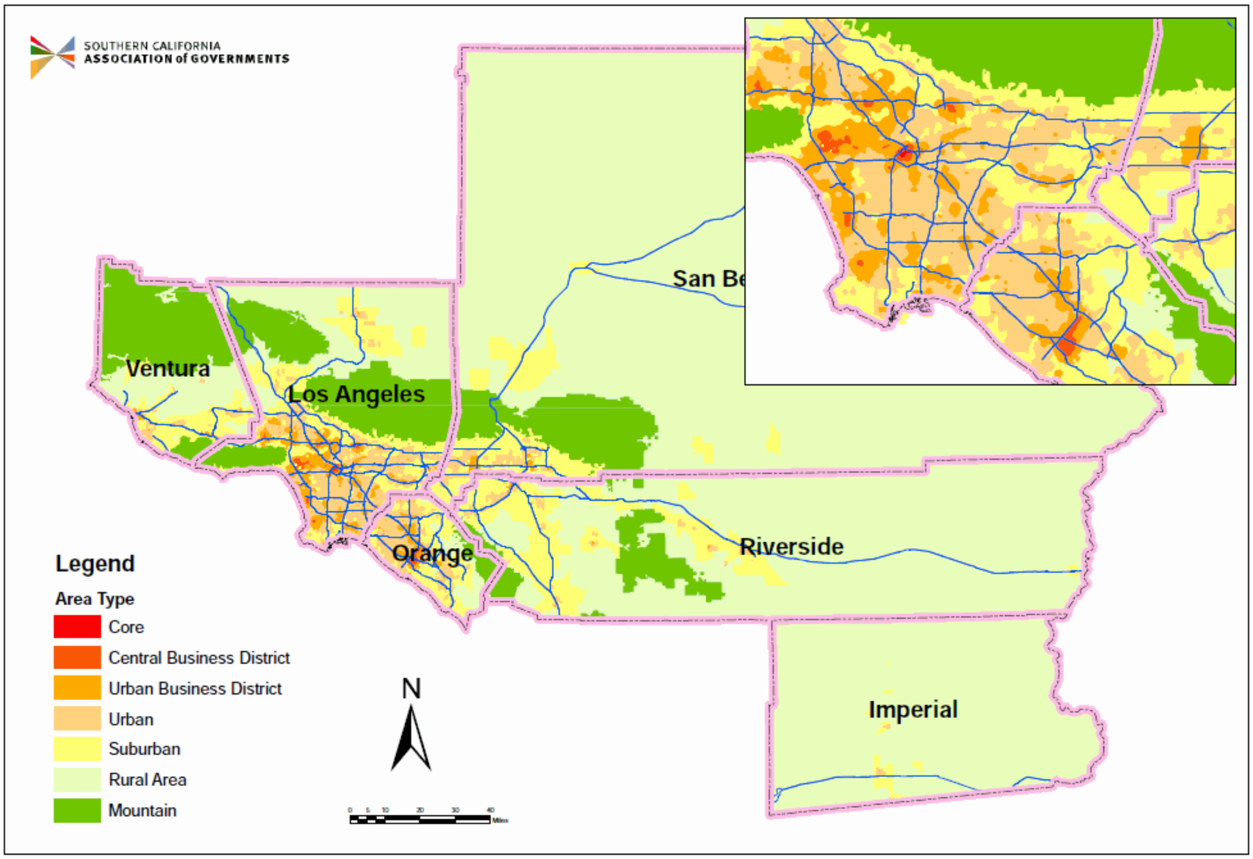
B. SCAG Area Type Map



Source: http://www.scag.ca.gov/modeling/pdf/MVS03/MVS03_Chap04.pdf.

C. LA MTA Model Speed and Capacity Lookup Table

Facility Type	Area Type	Number of Lanes	Capacity Per Hour, Per Lane	Free-Flow Speed (mph)
1	1	1	1,950	70
1	2	1	1,950	70
1	3	1	1,950	70
1	4	1	1,950	70
1	5	1	1,950	70
2	1	1	625	35
2	2	1	650	40
2	3	1	675	45
2	4	1	800	50
2	5	1	1,250	55
3	1	1	575	35
3	2	1	600	40
3	3	1	625	45
3	4	1	800	50
3	5	1	900	55
4	1	1	500	35
4	2	1	525	40
4	3	1	550	45
4	4	1	800	50
4	5	1	900	55
Multilane Specific				
2	1	>1	800	35
2	2	>1	850	40
2	3	>1	900	45
2	4	>1	1,000	50
2	5	>1	1,500	55
3	1	>1	650	35

Facility Type	Area Type	Number of Lanes	Capacity Per Hour, Per Lane	Free-Flow Speed (mph)
3	2	>1	750	40
3	3	>1	750	45
3	4	>1	900	50
3	5	>1	1,000	55
4	1	>1	550	35
4	2	>1	600	40
4	3	>1	625	45
4	4	>1	900	50
4	5	>1	1,000	55

D. GHG Emissions Calculator Constants and Assumptions

Project Type	Constant	Value	Citation/Explanation
Roadway Capacity	Number of week days/year	250	Assumes delay reduction benefits on holidays and weekends are marginal.
	Peak-period factor	32%	SCAG 2003 trip assignment model documentation.
	Hours in peak period	4	SCAG 2003 trip assignment model documentation.
	Auto occupancy (persons/vehicle)	1.7	NHTS (2009), Los Angeles-Riverside-Orange County MSA.
Interchange Capacity[1]	Ramp Capacity (per hour per lane)	1950	LA MTA Model Documentation– – Speed Volume Curve Equations.
	Ramp Free-Flow Speed (mph)	25	LA MTA Model Documentation– – Speed Volume Curve Equations.
	Peak hour to daily conversion	10	LA MTA Model Documentation.
Intersection Improvement	Proposed Signalized Intersection Cycle Length (sec)	60-120	FHWA Traffic Signal Timing Manual (2008)
System Operations[1]	% Turns from Exclusive Lanes from the Peak Direction	10%	HCM (2000), Intersection Turning Movements, Default Values in Absence of Turning Movement Data.
Transit Expansion	Headway Elasticity to Ridership Increase	-0.50	TCRP 95c9 (2004).
	Share of Wait Time as a portion of the Total Travel Time	22%	CUTR (1998), Table 4-13.
	Travel Time Reduction Due to Real Time Arrival	20%	TCRP 95c9 (2004).
	Elasticity of Transit Ridership WRT Transit Travel Time	-0.23	VTPI (2010).
	Average Trip Length (mi)	9	NHTS (2009) Los Angeles-Riverside-Orange County MSA (all trip types).
Park-and-Ride	Percentage of New Riders Utilizing Park-and-Ride Lots	37%	TCRP 95c18 (2004). Per FTA (2003), 37% of ridership are new riders.
Managed Lanes[1]	Elasticity of Transit Ridership WRT Transit Travel Time	-0.23	VTPI (2010).
	Managed Lane Capacity (per hour per lane)	1950	LA MTA Model Documentation– – Speed Volume Curve Equations.
	Managed Lane Free-Flow Speed (mph)	70	LA MTA Model Documentation– – Speed Volume Curve Equations.

[1] Number of week days/year, peak period factor, hours in peak period and auto occupancy use same values as roadway capacity approach.

ADT Adjustment Factor Lookup Table (Adopted from CARB (2005))

Non-University Area Project Length (mi)				University Area Project Length (mi)			
Max ADT	< 1	1– – 2	> 2	Max ADT	< 1	1– – 2	> 2
12,000	0.0019	0.0029	0.0038	12,000	0.0104	0.0155	0.0207
24,000	0.0014	0.0020	0.0027	24,000	0.0073	0.0109	0.0145
30,000	0.0010	0.0014	0.0019	30,000	0.0052	0.0078	0.0104

Activity Center Credits (Bike)

Activity center examples: Banks, churches, hospitals, park-and-ride, office parks, library, shopping, schools).

Centers	One-Half Mile
At least 3	0.0005
4 to 6	0.001
> 6	0.0015

Activity Center Credits (Pedestrian)

Activity center examples: Banks, churches, hospitals, park-and-ride, office parks, library, shopping, schools).

Centers	One-Quarter Mile
At least 3	0.001
4 to 6	0.002
> 6	0.003