KITTELSON & ASSOCIATES, INC./DOWLING
TRANSPORTATION ENGINEERING / PLANNING
180 Grand Avenue, Suite 250, Oakland, CA 94612 P 510.839.1742 F 510.839.0871

MEMORANDUM

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To: Alana Hitchcock, Caltrans HQ
Chris Ratekin, Caltrans HQ
Erik Alm, Caltrans D-4
Cesar Pujols, Caltran D-4
John McKenzie, Caltrans D-4
Tarek Hatata, SMG

From: Alice Chen, David Reinke
Project: Caltrans Smart Mobility Framework Implementation – Pilot Area 1
Subject: Preliminary Performance Measures for I-680 CSMP

1 Introduction

This memo presents our preliminary recommendations for Smart Mobility Framework (SMF) performance measures for the I-680 CSMP. Our recommendations are based upon review of the 17 SMF performance measures and their recommended metrics, as described in Exhibit 11 of the Smart Mobility 2010: Call to Action.[1] Our initial assessment and recommendation are based upon review of the recommended metrics, the relevance of the performance measure to the outcomes of the CSMP alternatives, and available tools and data to calculate the performance measures specific to the I-680 corridor.

Our recommendations for performance measures for this study are based on the following set of criteria:

- **Relevance** – Do the performance measures reflect the outcomes of the alternatives? Do the performance measures provide information on how to rank different project alternatives for the corridor? Are the performance measures directly related to the goals and objectives of this study?
- **Comprehensiveness** – Does the set of performance measures inform how well each alternative meets all objectives for the study?
- **Comprehensibility** – Are the performance measures sufficiently well-defined so that they are clearly understandable to decision makers and managers?
- **Data** – Are sufficient data available to determine the performance measures now and to forecast them in the future?

[1] Caltrans. *Smart Mobility 2010: A Call to Action for the New Decade*, February 2010.

Section 2 of this memo discusses our initial assessment of all 17 SMF performance measures. Section 3 presents the tools and data available for this study that are directly relevant to performance measures. Section 4 presents our preliminary set of performance measures for this study. Our preliminary recommendations include 8 SMF performance measures for further consideration. Section 5 describes the next steps for incorporating the corridor objectives. These performance measures will be revisited once the corridor objectives are defined and further data need assessment is conducted.

2 Initial Assessment of SMF Performance Measures

Table 1 below lists all 17 SMF performance measures that are being considered for the I-680 CSMP study. The table contains the performance measure as well as the recommended metrics directly from SMF. Our initial assessment on whether or not to include the performance measure in this study is based on the available data and tools for forecasting and assessing alternatives. For some performance measures, we also have recommended simplifying the metric in order to make the evaluation more understandable, as noted in the comments column.

It should be noted that the term "travel reliability" has been defined in various ways for different purposes. For this study we adopt the FHWA definition of travel time reliability as referring to the day-to-day difference in travel times subject to variations in traffic, weather, and other non-recurrent factors such as incidents that affect travel time.

2.1 Assessment of performance measures from other studies

A set of smart mobility measures from STARS was proposed for the Santa Cruz SR-1 corridor study project.[2] Due to funding considerations, the project was scaled back considerably and the measures were not used. The Santa Cruz MPO is, however, incorporating smart mobility measures into the RTP update. The proposed measures and our assessments for purposes of the I-680 CSMP are presented in Table 2.

[2] STARS: Sustainable Transportation Analysis & Rating System Pilot Plan Application Manual Version 1.0. January 10, 2012

Table 1. Initial Assessment of SMF Performance Measures

Goal	SMF Performance Measure	SMF Recommended Metrics	Assessment for CSMP	
			In-clude?	Comments
Location Efficiency	**1. Support for Sustainable Growth**	Consistency with regional Sustainable Communities Strategy or Alternative Planning Strategy meeting regional performance standards. Comparison of alternatives based on acres of land consumed, and relative reductions in induced VMT through: compact land use strategies, demand management, and network management.	N	Not likely to change across corridor alternatives.
	2. Transit Mode Share	Percentage of trips within a corridor or region occurring by bus, rail or by other form of high-occupancy-vehicle.	Y, with modifications	Transit share likely to remain low. Include ridesharing as part of measure. Source: CCTA travel model outputs
	3. Accessibility and Connectivity	Number of households within 30 minute transit ride of major employment center, within 20 minute auto ride of employment, within walking distance of schools. Weighted regional travel time and cost among trip producers and trip attractors.	N	Not well-defined. Locations of population and employment will not change across corridor alternatives. Accessibility is a function of travel time. Will be captured in travel time benefits measure.
Reliable Mobility	**4. Multi-Modal Travel Mobility**	Travel times and costs by mode between representative origins and destinations, aggregated over corridor or region.	Y, with modifications	Include as total travel time cost. Source: CCTA travel model outputs
	5. Multi-Modal Travel Reliability	Day-to-day variability of travel times between representative origins and destinations by mode, aggregated over corridor or region.	Y, with modifications	Current transit travel time reliability can be estimated from available data: PeMS for freeway reliability, CCCTA schedule adherence for current transit by line, BART data by station. Estimate current arterial reliability, future auto travel time reliability using models from SHRP 2 L03. No travel time data for bike or peds.
	6. Multi-Modal Service Quality (Level of Service: LOS)	Mode-specific and blended LOS measures of pedestrian and bicycle accommodation and comfort, transit availability and reliability, and auto travel efficiency.(1)	N	Auto LOS not recommended as a measure in STARS report. Multimodal LOS computed on individual mode-specific basis only, too data intensive for entire corridor.

Goal	SMF Performance Measure	SMF Recommended Metrics	Assessment for CSMP	
			In-clude?	**Comments**
Health and Safety	**7. Multi-Modal Safety**	Collision rate and severity by travel mode and facility, compared to statewide averages for each user group and facility type.	Y for current conditions only	Current highway crash data from SWITRS.
	8. Design and Speed Suitability	Conformance with guidance identifying suitable design elements and traffic speed with respect to mix of modes and adjoining land uses and area character.	N	Not sufficiently well defined. Data sources (design guidelines, codes) uncertain. Not changing land use.
	9. Pedestrian & Bicycle Mode Share	Percentage of trips within a corridor or region occurring by walking or cycling.	Y	Outputs from CCTA travel model by TAZ along corridor. Underestimates walk trips. Post-processing using NHTS-CA data for comparison
Environmental Stewardship	**10. Climate and Energy Conservation**	VMT per capita by speed range relative to State and regional targets.	Y	Use EMFAC for air pollution and GHG estimates. Cost out air pollution and GHG estimates using rates from accepted standard (Puget Sound Regional Council). Use VMT and average fuel economy to estimate energy consumption.
	11. Emissions Reduction	Quantities of criteria pollutants and GHGs	Y	Combine with previous
Social Equity	**12. Equitable Distribution of Impacts**	Impact of investments on low-income, minority, disabled, youth and elderly populations relative to impacts on population as a whole.	N	Difficult to identify disadvantaged populations. Can use TAZ income data to areas with higher than average percentages of low income households, but cannot identify other disadvantaged populations with existing four-step aggregate demand model.
	13. Equitable Distribution of Access and Mobility	Comparative travel times and costs by income groups and by minority and non-minority groups for work/school and other trips.	N	Same as (12)

Goal	SMF Performance Measure	SMF Recommended Metrics	Assessment for CSMP	
			In-clude?	**Comments**
Robust Economy	**14. Congestion effects on Productivity**	Time lost to congestion by trips that are economically productive and/or sustaining of essential mobility, measured as vehicle hours of delay (VHD).	N	Requires modeling effects of congestion on economic productivity. Still at forefront of economics research. This effect is captured in time value of congestion under (4)
	15. Efficient Use of System Resources	Additional VMT that are associated with economic productivity and/or sustaining of essential mobility compared with system expansion cost and impact.	N	Not well defined. Estimating relationship between economic productivity and travel is at the forefront of current economic research, but this would be far beyond the capabilities of existing analysis tools.
	16. Network Performance Optimization	VHD per capita, per lane mile, per private vehicle mile, per freight vehicle mile, per transit revenue mile, and in total.	N	STARS does not recommend delay as a measure. Calculate time cost of travel instead.
	17. Return on Investment	Person miles and revenue per lane mile of road, per transit revenue mile and per dollar invested (from all public and private funding sources). Comparison of alternatives based on benefits per dollar invested relative to: a) system user benefits (time and expense), and b) other Smart Mobility Performance Measures.	Y, with modificiations	Replace with benefit-cost measure: net present value or benefit-cost ratio

Source: Caltrans. Smart Mobility 2010: A Call to Action for the New Decade, Exhibit 11, p. 55.

Table 2. Assessment of recommended performance measures for Santa Cruz SR-1 corridor project

STARS Performance Measure	Proposed Metrics for I-680	Recommendations for CSMP	
		In-clude?	Comments
1. Reduce vehicle miles traveled	Total VMT from CCTA travel model	Y, with modifications	Main effects are reduced pollution emissions, energy use, operating costs. These effects are included in performance measures (9) and (10) in Table 1.
2. Prioritized funding for improvements to areas that have reported fatalities and injuries	Amount of money invested in areas with high crash rates	N	This is not an outcome-based measure. Use performance measure (7) from Table 1 instead
3. Improve travel time reliability	Same as performance measure (5) from Table 1	Y	
4. Improve speed consistency	Assess differences between average speeds, reliability measures for adjacent links on the system	Y, with modification	Replace with benefit-cost measure: net present value or benefit-cost ratio

3 Data sources and analysis tools

This section discusses the data sources and analysis tools for the I-680 corridor.

3.1 CCTA travel model

The CCTA travel model is currently being updated. It uses the same sub-models as the MTC 4-step regional travel model (BAYCAST). The following are the main features of the model:

- A finer TAZ structure in Contra Costa County and neighboring areas
- Outputs are produced for the following weekday time periods:
    - AM peak hour
    - 4-hour AM peak period
    - PM peak hour
    - 4-hour PM peak period
    - 16-hour off-peak period
- The mode choice model includes walk and bicycle. Walk and bicycle mode shares are sensitive to employment in the destination zone and to travel time based on distance and an assumed travel speed by mode. Walk and bike travel on the network are limited to non-freeway links. Bike travel between zones includes any special bike facilities, such as the Iron Horse Trail.
- Walk and bike trips are not assigned to the network.

As part of the CCTA travel model update a number of traffic count data were collected. In addition to PeMS data (see below), traffic counts, turning movements, and transit patronage data were collected:

- Peak-period vehicle turning movement counts were conducted at 349 intersections, 182 of which are within 5 miles of I-680
- Daily arterial counts were collected at 190 locations throughout the county; 110 of these locations are within 5 miles of I-680
- Counts from all PeMS stations within and near Contra Costa County for 2010
- Caltrans Census ramp counts for all freeway ramps in the area for 2009 and 2010
- Daily CCCTA patronage counts for each line
- BART station-to-station counts for peak and off-peak

3.2 Strategic Highway Research Program (SHRP) 2 L03

The SHRP 2 L03 project was completed in 2010.[3] The purpose of the project was to develop models of travel time reliability for freeways and arterials. Different models were developed for "data rich" and "data poor" areas depending on data availability.

The models predict the 99th, 97.5th, 95th, 80th, and 50th percentiles of the travel time index (TTI), which is defined as the ratio of actual to free-flow travel time. Models were developed

[3] Cambridge Systematics. SHRP 2 Project L03. Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies. September 2011. http://onlinepubs.trb.org/onlinepubs/shrp2/L35RFP/L03Report.pdf

for freeways and urban arterials. The models are sufficiently developed to allow their use in this study.

3.3 American Community Survey (ACS)

American Community Survey (ACS) provides place-to-place journey-to-work data for the 2006 – 2008 period. Detailed tables are available that split out work trips by mode, income, ethnicity, and other demographic factors. Data show place-to-place data for Census designated places with a population of 20,000 or greater.

ACS data also include a Public Use Microdata Sample (PUMS) data set, which consists of data on individual households and persons. Data include ethnicity, income, place of work, mode to work, and individual demographics. Because of confidentiality restrictions, geographic data within PUMS are grouped in areas of at least 100,000 population.

3.4 National Household Travel Survey – California Data (NHTS-CA)

As part of the 2009 NHTS-CA, additional households were surveyed to better understand non-motorized travel behavior throughout the state. A total of 18,000 additional samples were added for a total of 21,000 samples. Using the data, on-going research includes exposure rates for pedestrians and bicyclists by MPO. This sample size and level of detail is not applicable for local planning efforts, but provides information on non-motorized travel in the region.

3.5 California Active Transportation Safety Information Pages (CATSIP)

CATSIP is a state-supported site that provides resources to promote safety for pedestrian, bicyclists and other non-motorized road users in California.[4] The site includes crash data, such as the Transportation Injury Mapping System (TIMS) as well as laws and policies, such as a link to the California Strategic Highway Safety Plan, which has goals specific to bicycle and pedestrian safety under Challenge Areas 8 and 13.

3.6 Statewide Integrated Traffic Records System (SWITRS)

SWITRS is a statewide database on traffic crashes. The system provides detailed data on crash type, time, location, and lighting and weather conditions at the time of the crash.

3.7 Highway Safety Manual[5]

The Highway Safety Manual (HSM) contains a set of crash modification factors (CMFs) that quantify the change in expected average crash frequency as a result of geometric or operational modifications to a site that differs from set base conditions. Part D of the Highway Safety Manual provides a catalog of treatments organized by site type:

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[4] http://www.catsip.berkeley.edu/

[5] American Association of State Highway and Transportation Officials. Highway Safety Manual (3 vols.). 2010.

- Roadway segments
- Intersections
- Interchanges
- Special facilities
- Road networks

A further project, NCHRP 17-45, Enhanced Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges, was completed in August 2012. The project developed the following:

1. An overall framework for the enhancement of safety prediction methodologies for freeways and interchanges to support decision making for planning, network, corridor analysis, and individual site analysis
2. Safety analytical models and procedures within that framework
3. Models and procedures for a corridor and individual site application tool
4. Achapter for the future edition of the HSM
5. Documentation for inclusion of the models in the Interactive Highway Safety Design Model

The final report for this project has been accepted by the NCHRP panel and has been sent to AASHTO for balloting on whether to include the results in HSM.

4 Recommended Performance Measures

Our recommended performance measures were chosen according to the criteria:

- Can the performance measure inform decisions about what alternatives to choose, with reference to the overall goals?
- Is it measurable using existing data sources and tools?
- Can it be evaluated consistently against other performance measures?
- Is the total number of performance measures small enough to be comprehensible to decision makers?

The list of recommended performance measures is presented in Table 3.

The following are discussions of issues specific to some of the recommended performance measures.

4.1 Benefit-cost analysis: the rationale

An important recommended performance measure is benefit-cost: net present value or benefit-cost ratio, or both. Benefit-cost analysis provides a consistent method for valuing different project outcomes on the same scale; these outcomes include the following:

- Capital costs
- Operating and maintenance costs
- Air pollution and greenhouse gas costs (performance measures 10 and 11)[6]

[6] Performance measure numbers refer to performance measures listed in Table 1.

- User benefits: travel time savings and reliability (performance measures
- Return on investment (performance measure 17)

Benefit-cost analysis has several compelling advantages for this project:

- *It is comprehensive.* Benefit-cost analysis can incorporate a large number of seemingly disparate outcomes into a common measurement framework. Projects with different time scales can be compared directly by using discounting to compare net present values of benefits and costs.

- *It is consistent.* Benefit-cost analysis uses a fixed set of market values for project outcomes that can be monetized. These values are consistent across all projects. If there are uncertainties about valuations of some outcomes, such as value of travel time, a sensitivity analysis can be conducted to determine whether project rankings change with different values of outcomes.

- *It is understandable.* By providing a common measurement framework for many project outcomes, evaluation results are much easier to understand than if project outcomes were presented separately.

Caltrans provides a life-cycle benefit-cost spreadsheet model that can account for the following:[7]

- Capital costs
- Operating and maintenance costs
- Vehicle operating costs
- Air pollution emissions
- Highway and transit accidents
- User time benefits

The model does not account specifically for travel time reliability, but this can be incorporated with some modifications to the spreadsheets.

Table 3. Recommended Performance Measures for I-680 CSMP

SMF Performance measure		SMF Goal addressed	Recommended Metric	Data sources
2	Transit Mode Share	Location Efficiency	% of non-SOV trips (includes carpool/vanpools)	CCTA model
4	Multi-Modal Travel Mobility	Reliable Mobility	Total user-hours of travel times and travel costs by mode	CCTA model.
5	Multi-Modal Travel Time Reliability	Reliable Mobility	Travel time reliability measures by mode: buffer index, standard deviation; Travel time reliability relative to each mode	CCTA model, SHRP 2 L03 reliability models

[7] http://www.dot.ca.gov/hq/tpp/offices/eab/LCBC_Analysis_Model.html

7	Multi-Modal Safety	Health and Safety	Current, historical crashes by type	SWITRS,
9	Pedestrian & Bicycle Mode Share	Health and Safety	Bicycle and pedestrian mode share in corridor	CCTA model, adjust using NHTS-CA data
10	Climate and Energy Conservation	Environmental Stewardship	Emissions by pollutant type, including CO, O_3, NOx, CO_2	CCTA model, EMFAC
11	Emissions Reduction			
17	Return on Investment	Robust Economy	Benefit-cost: Net present value of benefits (travel time, reliability) minus net present value of costs (capital, O&M, air pollution, crashes)	Results of previous performance measures (2, 4, 5, 9, 10, and 11 above).

4.2 Multimodal travel time reliability

Research on travel time reliability has been predominantly concerned with highway travel time reliability, most recently the SHRP program. While we now have tools that can forecast travel time reliability for auto travel, we lack similar tools for forecasting reliability for other travel modes.

Auto travel time reliability can be estimated from the models developed as part of the SHRP 2 L03 study: Analytic Procedures for Determining the Impacts of Reliability Mitigation Strategies. The project produced two sets of models for estimating travel time reliability:

- "data poor" models are for situations where available data are limited; these are parsimonious models that rely on travel time index alone
- "data rich" models can be applied where the necessary forecast data are available; these include demand/capacity on the critical segment along a corridor, lane hours lost due to non-recurrent events, and rainfall

Details of the predictive models can be found in chapter 7 the final report for the project.[8] For freeways we recommend the use of the "data rich" models as follows. The following is an example of one of the "data rich" models; it forecasts the 95th percentile travel time index for the peak period as follows:

$$\log\left(TTI_{95}\right) = 0.23233 * dc_{crit} + 0.012350 * ILHL + *0.025315 * rain_{05}$$

Where

TTI_{95} = 95th percentile travel time index

dc_{crit} = "critical" demand-to-capacity ratio on the study section; i.e., the highest d/c ratio for all the links on the section

[8] Cambridge Systematics. SHRP 2 Project L03: Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies. September 2011.

$ILHL$	=	Annual lane hours lost due to incidents that occur within the time slice of interest (e.g., the peak period)
$rain_{05}$	=	Hours in the year where rainfall is ≥ 0.05 inches that occur within the time slice of interest

We recommend using the SHRP 2 L03 models as pivot-point elasticity models as follows:

1. Assume that rainfall is the same for base case and forecast periods
2. Estimate dc'_{crit} and $ILHL'$ for the forecast year. For example, if incident clearance times are reduced, the change in annual lane hours lost can be estimated from the results of the Caltrans non-recurrent congestion study (see below).[9]
3. Estimate the change in the 95th percentile travel time index using the following formula:

$$TTI'_{95} = TTI_{95}\left(\frac{dc'_{crit}}{dc_{crit}}\right)^{0.023233}\left(\frac{ILHL'}{ILHL}\right)^{0.12350}$$

where the primed quantities refer to the future year forecasts and the unprimed quantities refer to the measured base year values.

Incident clearance times can be estimated using the following data from the Caltrans non-recurrent congestion study:

[9] Dowling Associates, Inc. Measuring Non-Recurrent Traffic Congesiton. Report prepared for Caltrans. February 2003.

Incident Type	Blockage Type	Response Time (with FSP/without FSP)	Clearance Time	Total Duration (with FSP/without FSP)
Collision	Shoulder	5 min./30 min.	20 minutes	25/50 minutes
	One-Lane	5 min./30 min.	25 minutes	30/55 minutes
	Multi-Lane	5 min./30 min.	25 minutes	30/55 minutes
Breakdown	Shoulder	5 min./30 min.	20 minutes	25/50 minutes
	One-Lane	5 min./30 min.	15 minutes	20/45 minutes
	Multi-Lane	5 min./30 min.	15 minutes	20/45 minutes
Debris	Shoulder	5 min./30 min.	10 minutes	15/40 minutes
	One-Lane	5 min./30 min.	10 minutes	15/40 minutes
	Multi-Lane	5 min./30 min.	10 minutes	15/40 minutes
Truck Rear-end and Sideswipe	Shoulder, no injury			40 minutes
	Shoulder, with injury			55 minutes
	One-Lane			58 minutes
	Multi-Lane			126 minutes
Truck Hit Object, Broadside	Shoulder, no injury			55 minutes
	Shoulder, with injury			110 minutes
	One-Lane			62 minutes
	Two-Lanes			111 minutes
	Three+ Lanes			115 minutes
Truck Overturns				142 minutes

FSP = Freeway Service Patrol
From Caltrans Non-Recurrent Congestion Study, Exhibit 43.

Table 4. Incident durations

Bus transit service reliability is typically reported by a schedule adherence measure, such as percentage of bus arrivals at stops no later than five minutes after the scheduled arrival time. BART reports a patron-on-time measure: the percentage of riders who arrive at the destination station within five minutes of the scheduled arrival time. Unfortunately, there is no clear way to forecast transit service reliability because it is affected by unpredictable factors such as equipment reliability, driver availability, and passenger loading times in addition to traffic conditions. For certain types of alternatives, for example where express bus service on reserved right-of-way is being considered (e.g., express bus on HOV lanes), it is clear that the alternative would improve transit service reliability, but the degree to which it would do so would be difficult to quantify.

Bicycle travel time reliability is related in some ways to auto travel time reliability on surface streets. But bicycle often have the advantage that they can often travel while traffic is slowed or stopped. Hence, relating bicycle travel time reliability to auto travel time reliability is uncertain at best. As in the case of transit, alternatives involving dedicated facilities such as bike trails would increase bike travel time reliability, but this effect would be difficult to quantify.

Pedestrian travel time can probably be assumed to be reliable most of the time. Pedestrian wait times at signalized intersections depend on signal cycle times, which normally do not vary from day to day.

4.3 Forecasting pedestrian and bicycle trips

Pedestrian and bicycle trips have been notoriously difficult to forecast for several reasons:

- Household travel surveys, which provide the basis for developing travel forecasting models, typically under-report pedestrian and bicycle trips. This biases the mode choice model toward under-predicting pedestrian and bicycle mode shares.
- Pedestrian and bicycle trips typically account for a small share of total trip making. Mode choice models do not do a good job of forecasting very small mode shares.
- The majority of pedestrian trips and a large percentage of bicycle trips occur within the same TAZ. Intrazonal travel impedances are often estimated by ad hoc measures that do not take into account connectivity within a TAZ; hence, travel models typically do not forecast intrazonal trips very well.

One way to correct for these biases may be to develop one or more adjustment factors based on comparing actual pedestrian and bicycle counts to forecasts from the travel model, and adjusting the forecasts correspondingly. But such adjustment factors should be used with caution, as they would likely vary with the type of area (e.g., residential vs. business, downtown vs. outer area).

5 Next Steps

In addition to the criteria applied to develop this recommended list of SMF performance measures, these performance measures should support the overall planning objectives for the I-680 corridor. The SMF goals are aligned with the broad regional goals and objectives as presented at the July SWG meeting. Specifically, some of the regional goals and objectives that apply to the study area would include:

- **Increase the capacity** of existing highways and arterial roads through capital investments and operational enhancements. (CCTA 2009 CTP Strategy 1.1)
- Identify and implement strategies for **managing congestion** and **increasing multimodal mobility**. (CCTA 2009 CTP Strategy 1.2)
- Identify new strategies to **improve freight movements** on freeways and rail lines to **improve air quality** and the efficiency of shipping. (CCTA 2009 CTP Strategy 1.5)
- Help fund the **expansion of existing transit services**, and maintenance of existing operations, including BART, bus transit, school buses, and paratransit. (CCTA 2009 CTP Strategy 3.1)
- Promote formation of more **carpools and vanpools**, and **greater use of transit, bicycling, and walking**. (CCTA 2009 CTP Strategy 3.6)
- Management of freeway corridors to **facilitate regional travel** and to encourage interregional travelers to use the freeways and transit network rather than local and arterial streets (TRANSPAC 2009 Action Plan Tenet)
- Improved transit facilities and services to **provide mobility choices and alternatives to the single-occupant vehicle**. (TRANSPAC 2009 Action Plan Tenet)

As this group defines the corridor objectives, these recommended performance measures will be revisited and reviewed for consistency with the corridor objectives.