DRAFT

2016

Project Prioritization Criteria for the SHOPP Asset Management Pilot Program

California Department of Transportation

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Acknowledgments

The completion of the Asset Management Pilot Program marks a significant milestone in the implementation of asset management in California. This pilot program would not have been possible without significant support and contributions from numerous sources. The willingness of Caltrans employees to embrace the pilot program objectives is greatly appreciated. This pilot program challenged project proposers to be creative in developing new approaches to project justification in a short nomination time window. The nominations for this program were creative, innovative, and collaborative in nature. The subject matter expert review teams were challenged with developing objective data driven project evaluation criteria and testing the criteria on the project nominations. Over eighty subject matter experts were involved in developing evaluation criteria and scoring of the thirty seven project nominations. The five goal team leaders provided the guidance and perseverance to arrive at criteria that reflected the sometimes diverse perspectives of the team members. Their efforts are greatly appreciated. I would also like to acknowledge the contributions from the Division of Research and Innovation and System Information for the development of the Analytical Hierarchy Process tool and assistance drafting this report. Finally, the support of Director Dougherty, Deputy Directors and District Directors was instrumental in making this pilot happen. I would like to acknowledge and thank the many contributors from across the department who helped make this pilot a success.

Michael B. Johnson, P.E.

State Asset Management Engineer

Executive Summary

Caltrans has federal and state requirements to prepare a robust transportation asset management plan. This plan has to provide guidelines for the prioritization of projects in the State Highway Operation and Protection Program (SHOPP). Two pilot programs were initiated to lay the foundation for the development of these guidelines. The 2014 SHOPP Project Prioritization Pilot Program evaluated the viability of a Multi-Objective Decision Analysis (MODA) approach for the prioritization of disparate assets. The 2016 SHOPP Asset Management Pilot Program refined the project prioritization parameters, incorporated the Caltrans Strategic Management Plan 2015-2020 [10], and applied the revised model to multi-objective projects nominated under the pilot program. This report documents the 2016 SHOPP Asset Management Pilot Program project prioritization criteria and calculation methodology.

The 2016 SHOPP Asset Management Pilot Program began with a call for project nominations in July 2015. The nominations were required to include at least three different departmental assets or objectives and were capped at a maximum project value of $20 million. Each of the Caltrans twelve districts nominated at least one project under this pilot program. In total, 37 nominations were received. Five subject matter expert review teams were established to evaluate the nominated projects. Each team developed criteria to evaluate the nominated projects for one of the departmental strategic goals. The subject matter expert teams then applied their evaluation criteria to each of the nominations developing a score for each of the five strategic plan goals. The scores reflect how well the project contributes to the departmental strategic goals. Each project received five different scores corresponding to each strategic goal. An executive leadership group used the Analytic Hierarchy Process (AHP) to determine the weights for each of the five departmental strategic goals. A linear additive model then used the goal weights to combine the five goal scores into a single cumulative benefit. The weighted scores were adjusted using a magnitude factor to reflect the magnitude of the asset or objective which were improved. The projects' cumulative benefits were then divided by the projects' total SHOPP costs. The benefit to cost ratios were used to rank the projects from highest to lowest. Projects were selected from the top until the available planning target capacity of $100 million had been exhausted. In total, nine projects were selected to move into the formal planning process for possible programming in the 2018 SHOPP.

The 2016 SHOPP Asset Management Pilot Program resulted in the development of a transparent project prioritization criteria for the SHOPP, determined information that is needed at planning stages in order to perform the prioritization, tested the concept of funding multiple objectives in a single project, and established initial departmental strategic goal weights. The results from this pilot program will be evaluated by external academic decision analysis experts for potential improvements in the formation of the

objectives. Sensitivity analyses will be conducted to determine if the data driving the prioritization is appropriately influencing the overall results. An evaluation of the influence of traffic volumes will be undertaken to ensure that both rural and urban transportation projects are equitably competing. The findings from this external review will be used to improve the prioritization models for future application.

1 Introduction

Caltrans has Federal [1, 2] and State [13] requirements to prepare a robust transportation asset management plan. This plan has to provide guidelines for the prioritization of projects in the State Highway Operation and Protection Program (SHOPP). The 2016 SHOPP Asset Management Pilot Program project prioritization criteria marks a significant step toward the establishment of a transparent project selection criteria for the SHOPP.

The Project Prioritization Criteria 2016 aligned the project prioritization process with the five strategic goals which the Caltrans Strategic Management Plan 2015-2020 [10] established. These strategic goals are

1. Safety and Health
2. Stewardship and Efficiency
3. Sustainability, Livability, and Economy
4. System Performance
5. Organizational Excellence

The project prioritization criteria provides the following:

1. A methodology to determine a project's score toward each strategic goal
2. A methodology to evaluate a project's cumulative benefit toward all strategic goals
3. A top to bottom benefit-cost ratio ranking of competing projects in the SHOPP

This report is intended to capture the methodology used for project prioritization in the 2016 SHOPP Asset Management Pilot Program and should not be considered policy for the Department.

2 Background

Caltrans has historically defined projects by a single program element or accounting code which represents the funding source and implies the nature of the work and accomplishments. Examples of these program elements include safety improvement (201.010), bridge major rehabilitation (201.110), and pavement rehabilitation (201.121). Each of these programs has a primary purpose and one or more measures of performance related to the primary purpose. Program Managers are allocated a portion of the total SHOPP funds. Each Program Manager allocates his or her portion to projects which address the purpose of his or her program. This silo-based allocation approach has discouraged Program Managers from accommodating objectives other than the primary program objective. New guidelines are needed to shift the Department's current silo-based programming to a goal-oriented project prioritization process.

The 2014 SHOPP Project Prioritization Pilot Program started in July 2014 to propose a new methodology for the project prioritization process [3]. This pilot program found that a Multi-Objective Decision Analysis (MODA) framework is the appropriate approach to align the project prioritization process with the Department's strategic goals. The MODA approach provides a pathway around silo-based programming and provides a mechanism to evaluate all project benefits regardless of asset or objective combination included in the project. Using the MODA approach, a project receives credit for its contributions toward all departmental strategic goals and objectives. New goals and objectives, such as sustainability, which were never tied to the project prioritization process are incorporated. Overall, the MODA approach provides an improved and transparent project prioritization process. This pilot program concluded with a report in June 2015 [3].

In July 2015, the 2016 SHOPP Asset Management Pilot Program initiated a call to nominate multi-objective projects. The nominations were required to include at least three asset types or have benefits toward at least three departmental strategic objectives. As a result, each of the Caltrans twelve districts nominated at least one project, and a total of 37 nominations were received. The State Asset Management Engineer initiated five subject matter expert review teams. Each team was responsible for the following tasks for one strategic goal:

- Divide the goal into a number of underlying strategic objectives
- Determine the weight of each strategic objective within its strategic goal, independent from the other teams and the other strategic goals
- Define a methodology to calculate a project's score toward each strategic objective
- Present an equation which combines the objective scores into a goal score
- Apply the goal score equation to each of the 37 nominated projects and evaluate the overall soundness of the outcome

The efforts of the five subject matter expert review teams are summarized in Sections 3, 4, 5, 6, and 7. An executive leadership group was responsible for determining the weights of the departmental strategic goals and to calculate the cumulative benefits of the 37 nominated projects. The efforts of this group is summarized in Section 8. At the conclusion of this pilot program, the Project Prioritization Criteria 2016 was prepared.

3 Goal 1: Safety and Health

The Goal 1 subject matter expert review team was initiated to develop criteria to determine a project's score toward the strategic goal of Safety and Health. The Caltrans Strategic Management Plan 2015-2020 identifies the following objectives under this strategic goal [10]:

- Zero worker fatalities
- Reduce employee injury and illness rates
- Reduce user fatalities and injuries by adopting a "Toward Zero Deaths" practice
- Promote community health through active transportation and reduced pollution in communities.

Early discussions and analyses by this team focused on defining the objectives and available data for Safety and Health. Based on these discussions, it was determined that the four objectives were focused in three areas that could be scored; User Safety, Worker Safety, and Overall Health. The areas were weighted 40%, 20%, and 40%, respectively. The weighting of Worker Safety at 20% is a reflection of the fact that worker safety enhancements directly affect much less of the overall population of California. The remaining 80% was evenly divided between User Safety and Health. Below is the calculation for the overall score for Safety and Health.

$$Overall\ Safety\ and\ Health\ Score = (40\% * User\ Safety\ Score) + (20\% * Worker\ Safety\ Score) + (40\% * Overall\ Health\ Score)$$

3.1 Safety

3.1.1 User Safety

The development of the User Safety scoring criteria proved to be the biggest challenge for this subject matter expert review team. The team struggled with how to integrate location specific safety and systemic safety. It is important to note that reactive SHOPP safety projects are programmed under the 201.010 program. The User Safety scoring only considers proactive safety enhancements for the nominated projects.

3.1.1.1 Crash Modification Factors

For User Safety scoring for all modes, the team decided to use two criteria for scoring the nominated projects. First, the Federal Highway Administration's (FHWA) Crash Modification Factors (CMF) were used to develop an A through E rating for the effectiveness of safety countermeasures provided within a project. The CMF "is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site" [4]. The rating of project safety countermeasures by the team gives a combined qualitative and quantitative criteria for assessing the

nominated projects. The team's determination on the CMF criteria was rooted in the notion that proactive safety enhancements, and their degree of safety contribution, would be crucial to determining criteria for scoring the User Safety objective. Although all modes are considered, it should be noted that there is very little data available for bicycle countermeasures. The CMF scoring criteria is listed in the Appendix A. Table 3.1 shows a sample calculation of the CMF scoring criteria.

Countermeasure Effectiveness	*Scoring Equation*	*Number of Enhancements*	*Score*
'A' Enhancements	# x 1.0	2	2.0
'B' Enhancements	# x 0.8	0	0.0
'C' Enhancements	# x 0.6	3	1.8
'D' Enhancements	# x 0.4	1	0.4
'E' Enhancements	# x 0.2	3	0.6
Total Attribute Score			4.8

Table 3.1: Example of Crash Modification Scoring

3.1.1.2 Accident Rate

The second area of scoring this team used within User Safety was the accident rate within the project limits.

Note: If the project scores a zero for the CMF scoring, the accident rate is a non-factor and the project will score a zero for User Safety.

Initially, the team used the accident rate as a multiplier, but after some consideration, a more rigorous alternative was considered. The team determined that normalizing the ratio of the location specific accident rate and the average accident rate was the best way to account for context sensitivity and project specific data. This accident rates and average accident rates are available from the Highway Performance Monitoring System (HPMS). The final scoring equation is listed below:

$$Total\ User\ Safety\ Score = \frac{Crash\ Modification\ Factor\ Score_{Project}}{Maximum\ Crash\ Modification\ Score} + \frac{\frac{Accident\ Rate_{Project}}{Accident\ Rate_{State\ Avg}}}{Maximum(\frac{Accident\ Rate}{Accident\ Rate_{State\ Avg}})}$$

3.1.2 Worker Safety

Worker Safety scoring was approached by identifying the major factors that can increase worker safety. An internal review of fatality statistics dating back 1973 revealed five worker fatality common denominators. They are as follows:

1. Urban location

2. High Annual Average Daily Traffic (AADT)
3. Roadside work near shoulder
4. Vehicle parked on shoulder
5. Employee on foot

The subject matter expert review team first looked at urban location and High AADT. The assumption was made by the team that it is implied that a high AADT is in an urban location. Therefore, only AADT is considered in the scoring criteria. This data is available from the Highway Performance Monitoring System (HPMS).

Next, the team considered the final three fatality common denominators for worker exposure; roadside work near shoulder, vehicle parked on shoulder, employee on foot. In looking at these, the team determined that the exposure mainly has to do with the proximity to the traveled way and the duration of time spent in the work zone. Unfortunately, the data for proximity is not available. However, the Integrated Maintenance Management System (IMMS) does track the time spent by workers in the work zone. The average time spent within the project limits for each project nomination was used to calculate worker exposure risk. It was compared to the statewide average and a scale of low, medium, and high was developed.

Worker Exposure Scale	*Worker Hours (3 year average) / Mile of R/W*
High	>1000
Medium	500-1000
Low	<500

Table 3.2: Worker Exposure Scale

3.1.2.1 Project Location Risk Score

Using the worker exposure scale and the AADT, the team developed a scoring matrix. The team developed a scale that was consistent given the context. For example, a low AADT and medium exposure should score the same a medium AADT and low exposure. The scoring matrix is shown in Table 3.3.

Location	*High AADT (> 75,000)*	*Medium AADT (15,000 - 75,000)*	*Low AADT (< 15,000)*
High Exposure Time	7	5	3
Medium Exposure Time	5	3	2
Low Exposure Time	3	2	1

Table 3.3: Project Location Risk Score

3.1.2.2 Proactive Worker Safety Enhancements

The team then considered the actual enhancements each project provided to the Worker Safety objective. The enhancements are listed in Table 3.4. The table gives additional point allocation for the proactive worker safety enhancement additions for the projects. It is

important to note that if a project does not have any proactive worker safety enhancements the overall score becomes zero.

Proactive Worker Safety Enhancements	*Score*
≥ 3	3
2	2
1	1
0	Overall Score = 0

Table 3.4: Proactive Worker Safety Enhancement Scoring

Table 3.5 lists the proactive worker safety enhancements a project can provide. The list is derived from the SHOPP 201.235 program, "Roadside Safety Improvements".

Relocating and clustering existing facilities to safe work locations
Minor pavement for areas beyond the gore, slopes adjacent to bridge structures, low visibility areas, road edge, and narrow areas
Vegetation control treatment under existing guardrail
Inert materials to slopes and low visibility areas
Access gates, staircases, trails for light duty vehicles, and maintenance vehicle pullouts
Safety rails on retaining walls
Shielding of equipment that cannot be relocated
Removal of duplicative signage
Signage, lighting, and additional pavement at chain control
Safety Roadside Rest Area Water Quality Compliance for sewage and drinking water systems

Table 3.5: Proactive Worker Safety Enhancements

The final score for worker safety is determined by adding the project location risk score and the proactive worker safety enhancements score.

$$\begin{aligned} &Worker\ Safety\ Score \\ &\quad = Project\ Location\ Risk\ Score \\ &\quad + Proactive\ Worker\ Safety\ Enhancements\ Score \end{aligned}$$

3.2 Health

3.2.1 Air Quality

Air quality is considered in the scoring of projects. CalEnviroScreen guidance identifies ozone and Particulate Matter 2.5 as the two largest contributors to health threats. The guidance states [5]:

> *"PM2.5 Exposure Indicator Particulate matter pollution, and fine particle (PM2.5) pollution in particular, has been shown to cause numerous adverse health effects, including heart and lung disease. PM2.5 contributes to substantial mortality across California. The health impacts of PM2.5 and other criteria air pollutants (ozone, nitrogen dioxide, carbon monoxide, sulfur dioxide, and lead) have been considered in the development of health-based standards. Of the six criteria air pollutants, particle pollution and ozone pose the most widespread and significant health threats. The*

California Air Resources Board maintains a wide network of air monitoring stations that provides information that may be used to better understand exposures to PM2.5 and other pollutants across the state."

The subject matter expert review team also added diesel particulate matter to the analysis as it is identified in the Caltrans Strategic Management Plan 2015-2020 [10] along with NOx. NOx was not added to the analysis though, as data was not available. The readings for each were averaged by county and a scale (Good/Fair/Poor) was developed. The following is an example of this scale and ratings for ozone.

Statewide Average = 0.104	*Ozone Range: ozone concentration over the California 8-hour standard (0.070 ppm)*
Poor Air Quality	0.60-0.30
Fair Air Quality	0.29-0.10
Good Air Quality	0.09-0

Table 3.6: Example of Ozone Rating Scale

Poor	Poor	Good	Poor
Tulare	Fresno	Los Angeles	Riverside
0.39	0.32	0.08	0.42

Table 3.7: Example of Average Ozone Readings and Ratings by County

3.2.2 Active Transportation

Based on discussions among the team, it was determined that active transportation attributes would be essentially aligned with the complete streets features identified in the Project Delivery Assets database. In addition, it was recognized that in addition to active transportation attributes, a project could add benefit by reducing pollution. Therefore, "Solar Energy Use" was added to the list. These attributes are listed in Table 3.8.

New Sidewalk Installed
Rehabilitate Existing Sidewalk
New Sidewalk Bulb-outs
New Curb Ramps Installed
Repaired / Replaced Curb Ramps
New Accessible Pedestrian Signal (APS) System Installed
Retrofit Traffic Signal to Install APS System
New Pedestrian Refuge Islands
Upgrade Pedestrian Refuge Islands
New Class I bikeways (bike paths)
New Class II bikeways (bike lanes)
Restripe Bikeways
New Crosswalks
Modified Crosswalks
New Shoulders
Widen Existing Shoulders
Pave Existing Shoulders
New Bus Bays
New Non-motorized Overcrossing / Undercrossing for Accessibility
Upgrade existing Non-motorized Overcrossing / Undercrossing for Accessibility

Lightings
Bike / Ped Signage
New Sidewalk Installed
Solar Energy Use

Table 3.8: Active Transportation Attributes

Once the projects are analyzed for active transportation attributes and rated for air quality, the score is determined from Table 3.9.

Active Transportation Attributes	*Poor Air Quality*	*Fair Air Quality*	*Good Air Quality*
≥ 6	10	8	6
3-5	8	6	4
< 3	6	4	2

Table 3.9: Health Scoring

4 Goal 2: Stewardship and Efficiency

The Goal 2 subject matter expert review team was initiated to develop criteria to determine a project's score toward the strategic goal of Stewardship and Efficiency. The Caltrans Strategic Management Plan 2015-2020 identifies a number of objectives under this strategic goal [10], from which the following objectives have applications to the SHOPP:

- Effectively manage transportation assets by implementing the asset management plan and embracing a "fix it first philosophy".
- Effectively manage taxpayer funds and maximize the use of available financial resources.
- Assign ownership of transportation facilities, including roads and streets to the appropriate level of government.

From these strategic objectives, a number of performance measures are defined related to the condition of assets, leveraging the use of non-state funding sources, and relinquishment of appropriate transportation facilities. Each of these objectives have been incorporated into the project prioritization process as detailed below.

4.1 Asset Condition

Projects that extend the useful life of an asset or improve a deteriorated condition will be assigned a benefit score from zero to 10. A score of 10 would indicate a project that has the maximum possible condition benefit. The assigned scores shown in Table 4.1 take into consideration the starting condition of the asset and the expected benefit of the proposed project scope in a quasi life-cycle cost approach. For example, an asset in "poor" condition would receive minimal benefit from a preservation project, but would receive substantial benefit from a rehabilitation or replacement project. Rehabilitation and replacement are included in the same column to reflect the expectation that a project level life cycle cost analysis supports the selection between these options for a poor condition asset.

Pre-Project Condition	*Proposed Project Type*	
	Preservation	*Rehab / Replacement*
Good	5	1
Fair	8	5
Poor	2	10

Table 4.1: Condition Benefit Factor Matrix

The benefits shown in Table 4.1 are not adequate to make a project level determination by themselves without consideration of the size of the project. The magnitude of the asset being addressed by the project needs to be incorporated to scale the benefit so that it is in proportion to the project cost. The magnitude of the project effected by the benefit can be captured by using the unit replacement cost of the asset extended over the quantity being addressed in the project limits.

The scaled benefit is therefore determined by the following equations:

$$Condition\ Benefit = \sum Condition\ Benefit\ Factor * Quantity * Replacement\ Unit\ Cost$$

$$Scaled\ Benefit = Condition\ Benefit / Project\ Cost$$

The range of scaled benefits will be limited at 1.0 on the low end and 100 on the high end. Scaled benefits below 1.0 are of questionable value and benefits above 100 are limited for mathematical reasons. New additions to the transportation will utilize a factor of 1.0 to neither reward nor penalize necessary additions to the system.

4.2 Consequence of Conditional Failure

The potential traffic impact of conditional failure of the various assets are not the same. The prioritization methodology needs to reflect this in the scoring. For example, the impact to the highway of a culvert washout is significantly more than the failure of loop detector. Projects with multiple assets shall take the consequence score of the most critical asset.

System Impact Factor	*Asset / Activity*	*Score*
Potential highway closure or long detour (>20 mi) over an extended period of time (>5 days)	Bridge rehabilitation / replacement of poor condition bridge that carries highway traffic. Scour mitigation of scour critical bridges. Bridge seismic - Tier 1 seismic bridge. Culvert rehabilitation / replacement of poor condition culvert. Facilities - fire, life, and safety projects.	2
Short term closure or short term partial highway lane capacity loss	Pavement - Rehabilitation of poor condition pavement (2R, 3R) only. Bridge seismic - Tier 2 or higher seismic bridge needs.	1.5
Failure of asset does not significantly impact highway capacity	All other assets / activities	1

Table 4.2: Consequence Factor

4.3 Traffic Volume and Freight

The magnitude of total two directional traffic volume and truck traffic needs to be considered in prioritizing where investments should be made. If all other factors are equal, priority should go to the projects on higher volume routes or routes that have more truck traffic. This component of the overall score should be structured in a way that it does not disfavor lower volume routes to a level that makes qualifying for project funding contrary to life cycle cost principles. The following table should be used to weight the significance of the condition on the number of vehicles impacted. Use the higher of the scores for total traffic volume and truck traffic volume.

Average Daily Traffic	*Average Daily Truck Volume*	*Score*
>200,000	>14,000	10
200,000>ADT>130,000	14,000>ADTT>12,000	9
130,000>ADT>75,000	12,000>ADTT>10,000	8
75,000>ADT>35,000	10,000>ADTT>8,000	7
35,000>ADT>25,000	8,000>ADTT>6,000	6
25,000>ADT>15,000	6,000>ADTT>4,000	5
15,000>ADT>7,500	4,000>ADTT>2,000	4
7,500>ADT>5,000	2,000>ADTT>1,000	3
5,000>ADT>2,500	1,000>ADTT>500	2
2,500>ADT	500>ADTT	1

Table 4.3: Traffic Factor

4.4 Project Funding

The Caltrans Strategic Management Plan 2015-2020 reflects a desire to leverage funding from sources outside of the State Highway Account to the maximum extent possible [10]. External funding sources extend the benefits of SHOPP projects on the State Highway System and at the same time improve partnering and coordination with local transportation interest. Projects eligible for federal funding are specifically encouraged in the Caltrans Strategic Management Plan 2015-2020. Given the diverse set of assets managed in the SHOPP and the variety of potential funding source outside of the State Highway Account, the funding scoring matrix in Table 4.4 is proposed.

Funding Type	*Score*
Federal Funding plus non-SHOPP Funds	5
Federal Funding Eligible (88%)	4
State Funds plus > 50% non-SHOPP contribution	3
State Funds plus 1-49% non-SHOPP contribution	2
State only funding	1

Table 4.4: Project Funding Matrix

4.5 Combining Stewardship Factors

The stewardship factors noted above shall be combined using the following weighted formula:

$$Overall\ Score = Consequence\ Factor * (0.5 * Condition\ Factor + 0.3 * Traffic\ Score + 0.2 * Funding\ Score)$$

Scores will be further normalized to a 0-100 rating scale for combination with other goal scores.

4.6 Relinquishment of Asset

The Stewardship and Efficiency goal also includes an objective to assign transportation facilities to the appropriate level of government. The SHOPP has a program specifically geared toward the relinquishment of assets. In many cases, targets of relinquishments may

require some level of work necessary to bring the asset to a “state of good repair” prior to relinquishment of the asset. Caltrans Planning unit has developed a statewide listing of relinquishment targets; however, proposed legislation SB 254 would require the California Transportation Commission to approve any proposed relinquishments of transportation facilities. In light of the uncertainty related to relinquishment authority, and the typical nature of relinquishment needs in the SHOPP and the Minor Program funding for relinquishments under current funding constraints, this item will be excluded from project level prioritization at this time.

5 Goal 3: Sustainability, Livability, and Economy

The Goal 3 subject matter expert review team was initiated to develop criteria to determine a project's score toward the strategic goal of Sustainability, Livability, and Economy. The Caltrans Strategic Management Plan 2015-2020 identifies the following objectives under this strategic goal [10]:

- People — Improve the quality of life for all Californians by providing mobility choice, increasing accessibility to all modes of transportation and creating transportation corridors not only for conveyance of people, goods, and services, but also as livable public spaces.
- Planet — Reduce environmental impacts from the transportation system with emphasis on supporting a statewide reduction of greenhouse gas emissions to achieve 80% below 1990 levels by 2050.
- Prosperity — Improve economic prosperity of the State and local communities through a resilient and integrated transportation system.

Each of these objectives includes four performance measures. All of these performance measures have application to the project prioritization process. Initial application of the performance measures will be more qualitative than quantitative.

5.1 Tool Research

Evaluation of sustainability factors in projects is a new way of looking at transportation priorities, and the best practices for project scoring for sustainability are limited. The Caltrans Division of Research, Innovation, and System Information performed two Preliminary Investigation studies on sustainability tools [11, 12]. These studies included several sustainability measuring tools. The subject matter expert review team reviewed two newer tools currently being used around the country: INVEST, and Envision.

INVEST 1.0: A self-evaluation scoring system, developed by FHWA, and has three independent modules that can be used to evaluate transportation services: system planning, project development, and operations and maintenance. Each module has a variety of criteria (scorecards) to score a project. Each criterion is tied to a leg of the triple bottom line. Point value is driven by the potential impact on sustainability. The Department's pilot using INVEST 1.0 determined that this tool was a broad programmatic indicator and more useful to begin the Department's implementation of sustainability. It did not appear to be a tool ready for the project prioritization process.

Envision: Created by a strategic alliance of the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design, and the Institute for Sustainable Infrastructure, and was designed as a project assessment tool. It evaluates, grades, and gives recognition to infrastructure projects that use transformational,

collaborative approaches to assess sustainability indicators over the course of a project's life cycle.

5.2 Tool Development

After a careful review of the two products examined in the research, the subject matter expert review team chose Envision as the basis for the scoring tool. It was preferred because of its similarity to the Leadership in Energy and Environmental Design (LEED), which is one of the most popular green building certification programs used worldwide. LEED is a fairly well known green building rating tool. Envision had been vetted by the engineering community to evaluate a broad spectrum of infrastructure projects, and includes an optional use of third party scoring, addresses relevant topics, and contains a free scoring tool and free simple checklist.

The team pared the sixty questions in the Envision checklist down to twenty questions. These questions were then tied to the sustainability performance measures in the Caltrans Strategic Management Plan 2015-2020 with emphasis on people, planet, and prosperity. The team considered the qualitative nature of the twenty questions as a beginning point to encourage the Caltrans districts to consider and to understand sustainability elements. The team however intends to move toward outcome-based performance measures that are extensively quantitative in nature in the future cycles. The following elements were included in the twenty questions:

5.2.1 People

The following four performance measures from the Caltrans Strategic Management Plan 2015-2020 target "People":

- Bike, pedestrian, and transit increase
- Accessibility score
- Livability score
- Sustainable corridors

Six (30%) of the twenty questions, with a possible score of five for each question, addressed "People". The "People" questions ask whether the nominated project provides any of the following:

- Access to adjacent facilities, amenities, and transportation hubs, including way finding signage
- Encourages the use of transit and / or non-motorized transportation
- Coordinates the design with other infrastructure assets to improve walkability and livability

- Enhances of public spaces, or addresses Section 4(f) properties (examples include parks, plazas, recreational facilities, or wildlife refuges) to enhance community, livability, and quality of life
- Context Sensitive Solutions view of the project
- Seeks input from local stakeholders on impacts or enhancements to community infrastructure

5.2.2 Planet

The following four performance measures from the Caltrans Strategic Management Plan 2015-2020 target "Planet":

- Per capita vehicle-miles traveled reduction
- System pollution reduction (air and energy)
- Operational pollution reduction (air, energy, and water)
- Improve green infrastructure score

Eight (40%) of the twenty questions, with a possible score of five for each question, addressed "Planet". The "Planet" questions ask whether the nominated project provides any of the following:

- Reduces energy consumption or generates energy supply
- Storm water treatment requirements
- Improvements to roadside vegetation through restorative actions to native / appropriate vegetation to reduce / eliminate need for future management (maintenance, water use, pesticides, invasive species, etc.)
- Based on a life-cycle carbon assessment, substantially reduces carbon emissions
- Includes green infrastructure, such as reducing heat island effects by reducing the percentage of low solar reflectance index (SRI) surfaces
- Preserves, improves, or connects important natural resources (habitat, species needs, or fish and wildlife movement corridors)
- Improves or enhances existing agricultural conditions or associated interface with the transportation facility (water conveyance, quality, habitat preservation, weed management, farming operation, etc.)
- Avoids or minimizes impacts on historic and cultural resources

5.2.3 Prosperity

The following four performance measures from the Caltrans Strategic Management Plan 2015-2020 target "Prosperity":

- Prosperity score
- Freight efficiency score

- Resiliency score (climate change, system, and financial)
- Resources consumption reduction (materials and potable water)

The final six (30%) of the twenty questions, also with a possible score of five for each question, addressed "Prosperity". The "Prosperity" questions ask whether the nominated project provides any of the following:

- Addresses potential risks or vulnerability deficiencies identified in state, regional, local, or site specific plans (i.e. for climate change, extreme weather, etc.)
- Enhances the community's quality of life and economic prosperity
- Priority freight network included in the Freight Mobility Plan
- Reuses existing materials or recycled materials or use of materials from within 100 miles of the project site
- Addresses or enhances adjacent wetlands, hydraulic connection, and water functions, values, or existing deficiencies
- Allows for natural floodplain functions to be restored or rectified related to existing infrastructure impingements

5.3 Scoring

The scoring sheet developed by the subject matter expert review team provided a minimum of five possible non-exclusive answers, listed "a" through "e", for each of the twenty questions. Each appropriate answer received one point. If all five or more answers applied, the nominated project received the maximum five points for the question. Some questions had a tiered approach with a minimum criteria of "a", and each subsequent criteria built upon its base.

For example, one of the twenty questions asked, "Will the proposed project make meaningful enhancements to public space, or address Section 4(f) properties (examples include parks, plazas, recreational facilities, or wildlife refuges) to enhance community, livability, and quality of life?" The nominated project received one point if any of the following five answers applied:

a. Minimally recognizes any 4(f) property and how project scope addresses initial idea of how to integrate into project consideration, including publicly-owned public parks, recreational areas, or wildlife or waterfowl refuges, or historic sites.
b. Contributes to meeting local, regional, or general plan (recreation / bike / ped / goals).
c. Provides linkage to public space (making connection with bike path or road, trail system, adjacency to state park, wildlife refuge, etc.), enhances or leaves in better condition at end of project / construction.

d. Identifies a goal of the project to include avoidance of 4(f) use or leaves in better condition at end of project / construction.
e. Consulted with the official jurisdiction over 4(f) property.

In addition to a score, a summary feedback sheet, citing strong and weak features, was prepared for each project. The feedback was designed to address two important goals. The first goal was to improve the evaluation process, so the most sustainable projects are highly rated, and the second goal was to educate those preparing project documents about how to clearly identify and present the most sustainable projects. Sustainability has not been a major focus of project selection in the past, so addressing sustainability will be an ongoing learning process.

5.4 Cross-Goal Issue

One issue which was raised was the potential overlaps or duplications in the performance measures for greenhouse gas emissions which are included both under Overall Health in the Safety and Health goal and under Planet in the Sustainability, Livability, and Economy goal. The Overall Health objective evaluates greenhouse gas emissions by measuring components of the infrastructure that contribute to active transportation. The Planet objective evaluates greenhouse gas emissions by measuring CO2 emissions. These are two very different measures with very different outcomes and do not appear to be overlapping or duplicating.

A similar issue was raised with the bike and pedestrian targets which are both under sustainability and under the Overall Health objective. Since it is not an issue to consider vehicles across multiple goals, it should not be an issue with other modes of transportation, such as bike and pedestrian.

6 Goal 4: System Performance

The Goal 4 subject matter expert review team was initiated to develop criteria to determine a project's score toward the strategic goal of System Performance. The Caltrans Strategic Management Plan 2015-2020 identifies the following objectives under this strategic goal [10]:

- Delay reduction
- System reliability
- Corridor management and integration
- Complete streets

6.1 Delay Reduction

Projects which have features which contribute to the reduction of delay at 35 mph will score on a scale of 0 to 10 according to Table 6.1, depending on the amount of delay the facility currently has, and depending on the delay reducing features the project proposes. A score of 10 indicates that a project location is currently experiencing very high levels of delay, and that the project will add a feature that has the most significant impact on delay reduction. Scores can vary based on the severity of existing delay, and the effectiveness of the project features. Projects which add no features intended to impact delay will receive a score of 0.

	Corridor Hours of Delay at 35 mph (most recent quarter)		
	> 100,000 hrs	*10,000 - 100,000 hrs*	*< 10,000 hrs*
High Value Activity	10	8	3
Medium Value Activity	7	5	2
Low Value Activity	2	2	1

Table 6.1: Delay Reduction Scores on a Scale from 1 - 10

Delay at 35 mph is currently assessed and compiled into the Caltrans Division of Traffic Operation's Annual / Quarterly Mobility Performance Statistics [6]. Each district posts its most delayed corridors for the last three months. In the event that a corridor does not have its delay posted, delay can be calculated by the Caltrans Performance Measurement System (PeMS), and if an area is outside of an urban area, the assumption is that the quarterly delay at 35 mph is below 10,000 hours, unless it can be calculated or estimated by other means.

Activities affecting delay are based on the general effectiveness of reducing delay in congestion scenarios. Activities have been grouped into high, medium, and low value according to Table 6.2, and have been assessed by headquarters and districts mobility staff. In the event that a project includes multiple activities, the highest value activity should be used for this calculation.

High value activities	High volume relief (hard shoulder running, switchable lanes)
	Auxiliary lanes
	Ramp metering
	Signal timing upgrades
	Connected or integrated corridor systems
	Connection or intersection improvements
	Managed lanes
	Upgrade, replace, or add new detection (part of a TMS system, completing a system)
Medium value activities	Support incident response (CCTV, associated communications, TMC upgrades)
	Roundabouts
	Strategies supporting bus or rail usage
	Strategies supporting active transportation (bike & ped)
	Improve communication / Fiber replacement
	CMS or EMS signs
Low value activities	Turn lane reconfigurations
	Park and ride facilities

Table 6.2: High, Medium, and Low Value Activities

6.2 System Reliability

The System Reliability score is based on a combination of the existing reliability condition, along with the project feature that improves reliability. This is similar to the Delay Reduction objective, but the calculation of need and the value of the project assets are different.

High value activities	Auxiliary lanes
	Support incident response (CCTV, associated communications, TMC upgrades)
	High volume relief (hard shoulder running, switchable lanes)
	Connected or integrated corridor systems
	Connection reconfigurations
	Signal timing upgrades
	Ramp metering
Medium value activities	Upgrade, replace, or add new detection (part of a TMS system, completing a system)
	CMS or EMS signs
	Improve communication / fiber replacement
	Safety improvements
Low value activities	Park and ride facilities
	Managed lanes
	Turn lanes
	Rural roundabouts

Table 6.3: High, Medium, and Low Value Activities

The current state of the project location is based on the reliability calculation. The subject matter expert review team used corridor Buffer Time Index (BTI) to assess the level of reliability of the location. The BTI is a measure of the variability of travel times, and can be calculated in the Caltrans PeMS. The worse of the AM (5 am – 10 am) or PM (3 pm – 8 pm) commutes should be used, and if the project affects both directions of traffic, the worst directional BTI calculation should be used. In areas where there is no highway detection,

the system should be considered reliable, unless the engineer has calculated a BTI that shows otherwise.

Activities are organized in high, medium, and low values according to Table 6.3 depending on the amount of influence an improvement would have on System Reliability. While there is a significant amount of overlap with the features that contribute to Delay Reduction, System Reliability relies heavier on features that help with clearing out systems of non-recurrent delay.

Reliability improvement scores range from 0 to 10 according to Table 6.4. In the event that a project includes multiple activities, the highest value activity should be used for this calculation.

	Corridor Buffer Time Index (most recent 3 months)		
	> 0.4 (unreliable)	*0.2 - 0.4 (mod reliable)*	*< 0.2 (reliable)*
High Value Activity	10	7	3
Medium Value Activity	7	5	2
Low Value Activity	3	2	1

Table 6.4: System Reliability Scores on a Scale from 1 - 10

6.3 Corridor Management and Integration

This objective reflects how well a project will maximize the integration and operation of the transportation system as well as the integrated corridor management strategies. This objective is mainly based on the location of the project, and favors projects which contribute to a corridor that is ranked highly because of its delay or the amount of vehicle-miles traveled on that corridor.

A project can only score in this objective if it has also scored at least one point in either the Delay Reduction or the System Reliability objective. Otherwise, it scores zero. The total possible points in this category is 10.

The bulk of the Corridor Management and Integration score is based on whether the project falls on one of the Department's top priority corridors. Depending on its position on the list, it can score from 0 to 8 points, as shown by Table 6.5.

Top Congested Corridor	*Tier*	*Score*
01-05	1	8
06-15	2	5
16-26	3	3
27-50	4	2
51-100	5	1
Other	6	0

Table 6.5: Corridor Management and Integration Scores

The project can score an additional point if it has a headquarters approved partnership or an integrated corridor management plan within its project limits. It can also score an additional point if it is on a truck or interregional route.

6.4 Complete Streets

The intent of the Complete Streets objective is to elevate projects with complete street features which are designed as part of a collaborative, multi-modal transportation solution supporting a region's transportation vision. These regionally supported projects provide a seamless, interconnected transportation system that provides safe and accessible active transportation modes from and to destinations. These systems improve a region's livability and revitalize communities. Integrating complete street elements is an integral component of designing a sustainable, multimodal system that considers land use, context, destinations, safety, environmental stewardship, and life-cycle fiscal investments. To achieve this transportation system, Caltrans should work with its transportation partners early in planning and project development to identify community, environmental, and aesthetic considerations. This approach ensures that transportation and land use concerns are addressed before projects are scoped, programmed, and constructed.

The nominated projects are rated by the number of complete street features from the FHWA's safety countermeasures from its Pedestrian and Bicycle Safety Guide and Countermeasure Selection System [7]. These treatments have been proven effective. The effectiveness of each of the countermeasures on pedestrian crashes and safety has been documented in a separate report, "Evaluation of Pedestrian-Related Roadway Measures: A Summary of Available Research" [7].

Each nominated project is reviewed, and complete street features are tallied in eight categories of "Facility Location and Purpose" with a maximum count of two for each countermeasure type. The eight categories are

1. Along Roadway
2. Crossings
3. Intersection Design
4. Roadway Design
5. Signals and Signs
6. Traffic Calming
7. Transit
8. Other Treatments Appropriate to Location

The complete streets tally sheet from FHWA's Pedestrian and Bicycle Safety Guide and Countermeasure Selection System [7], filled out for a sample project, is presented in Appendix H. For projects identified in a regional or local transportation plan or equivalent,

the score receives a bonus of 0.2. The total number of points possible on this goal after being normalized is 10.

6.5 Final Score

The four components of the System Performance goal have equal weights. After the four objective scores are averaged, a goal score from 0 to 10 will be obtained.

7 Goal 5: Organizational Excellence

The Goal 5 subject matter expert review team was initiated to develop criteria to determine a project's score toward the strategic goal of Organizational Excellence. The team identified four objectives under this strategic goal. These objectives sustain the Department as a strong and effective organization through

- Enabling employee engagement and innovation
- Fostering collaboration
- Encouraging skilled communication
- Supporting effective decision making through the application of risk management.

Traditionally, the work environment cultivated around projects has been thought of in terms of occupational health and safety and employee health promotion. However, the missing piece which the Organizational Excellence goal can provide is to encourage a comprehensively healthy and high performing work environment by bringing into focus elements of organizational health in areas such as leadership, employee recognition, learning and growth, collaboration, communication, and effective decision making at the project initiation level. Adding these criteria to the project prioritization process encourages management action and team dynamics which will ultimately support the successful delivery of a project.

The scoring rubric for each of the four objectives is based on documentable products. In addition, a rubric of qualitative expectations is developed for when a project is selected for programming and delivery is initiated. The inclusion of this supplementary rubric, which further develops expectations of organizational maturity, is meant to provide guidance to encourage ongoing self-evaluation and review by the project development teams. The maximum number of points for the Organizational Excellence goal is twenty. After a project's total number of points is calculated, a multiplier of five is applied to obtain a normalized score between 0 and 100 for this goal.

7.1 Employee Engagement and Innovation

Under Employee Engagement and Innovation objective, a project receives two points if it identifies new or creative / innovative ways of doing things.

7.2 Collaborative Partnerships

Under Collaborative Partnerships objective, a project receives

- One point if it identifies partners
- Two points if it has a formal outreach plan
- Three points if it has a collaborative agreement.

The maximum number of points for this objective is six.

7.3 Skilled Communication

Under Skilled Communication objective, a project receives

- One point if it identifies target audience
- Two points if it develops a communication plan
- Three points if it has outreach activities with target audience.

The maximum number of points for this objective is six.

7.4 Effective Decision Making through Risk Management

Under Effective Decision Making through Risk Management objective, a project receives

- One point if it identifies / assesses risks
- Two points if it manages risks
- Three points if it certifies risks.

The maximum number of points for this objective is six.

7.5 Qualitative Self-Evaluation Rubric

A rubric of qualitative expectations is developed in Table 7.1. It applies to projects when their programming phase is complete and the delivery phase is initiated.

Collaborative Partnerships	
Emerging	○ Partners / stakeholders (participants, community partners, funders, advocates, champions) are not fully identified or engaged in partnership development. ○ Planning is inconsistent and one-sided; does not allow for full partner involvement or benefit. ○ Partners understand the foundation for the partnership, but a Shared Agreement of the "three R's" (roles, responsibilities, resources) does not exist. ○ Activities, outcomes, and programming of the partnership are not rooted in community needs. ○ Partners operate moment-to-moment with limited discussion of the future.
Developing	○ Planning of partnership activities involves collaboration among partners. ○ Partners have identified the needs that will be addressed through the partnership. ○ A Shared Agreement is in development, but not all pieces are clearly defined. ○ Identified stakeholders begin to participate in the planning and implementation of partnership activities. ○ Partners have identified key community members / stakeholders to engage in partnership process.
Transformative	○ Partners meet on a regular basis to maintain the relationship, to determine outcomes, and to create plans to address identified needs. ○ A Shared Agreement document exists; indicating mutual understanding and commitment to the three R's. ○ Opportunities are intentionally created to support ongoing stakeholder engagement. ○ Partners mobilize and build on community assets by fully engaging community members / stakeholders. ○ Partnership actively works toward mutually beneficial outcomes; those outcomes are clearly understood and publicly communicated.

Employee Engagement and Innovation	
Emerging	○ A climate of engagement may be evident. Feedback is patchy between employees and management. A system of informal recognition and rewards may be evident. ○ A one-time feature, product, organizational structure is adopted. ○ Innovation practices are haphazard, or not aligned with Caltrans strategic goals.
Developing	○ An engaging work climate is evident. Feedback is more consistently evident between staff and management. Use of informal recognition is evidenced and somewhat consistent. ○ A process of innovative thinking or continuous process improvement is evident, but inconsistent. ○ Innovation practice may be connected to Caltrans strategic goals, but may sometimes "stretch". ○ Hypothesis-based engagement of problems and processes are consistently evident on the project. ○ It is evident that retrospective review of what is or has been is occurring. ○ Only problems with lower levels of uncertainty are engaged. ○ Hard, measurable evidence is used as part of proposals for innovative suggestions.
Transformative	○ A climate of engagement is clearly evident throughout the life of the project. Positive encouragement and reinforcement are clearly evident. Meaningful informal and formal recognition and rewards are paired with performance outcomes. ○ A consistent process of innovative thinking and continuous process improvement is evident. ○ Innovation practice is clearly connected to Caltrans strategic goals. ○ Innovation process is exploratory. ○ Questions are posed and response is driven by what is to come, not just what is and what has been. ○ Problems with higher levels of uncertainty are addressed. ○ Qualitative information is used as a complement to hard, measurable evidence.

Effective Decision Making through Risk Management	
Emerging	○ Are not able to go beyond the guidelines of mandated risk activities. ○ Selects some inappropriate mitigating actions; may select actions solely based on cost or ease of implementation. ○ Addresses only surface-level or obvious risks; addresses only some of the categories of risks. ○ Minimally explores options to mitigate risks; only explores options for the most basic risks.
Developing	○ Demonstrates some independence in going beyond the guidelines of mandated risk activities. ○ Selects mostly appropriate mitigating actions; somewhat considers the prior risk identification and assessment. ○ Brainstorms options to mitigate most of the risks. ○ Consults with some constituents; demonstrates some consideration for their input. ○ Establishes basic plans for managing emergencies.
Transformative	○ Demonstrates independence in going beyond the guidelines of mandated risk activities. ○ Ensures that all constituents adhere to pre-established risk management plans. ○ Clearly communicates details and purpose of risk management plans; provides resources or materials to constituents. ○ Consults with all relevant constituents; draws appropriate conclusions from their input and advice. ○ Develops clear and thorough contingency and crisis response plans.

Skilled Communication	
Emerging	○ Communication flows mostly one-way; there is a lack of exchange between partners. ○ A system for sharing work between partners is not in place or prioritized.
Developing	○ Two-way communication takes place informally between partners, but does not contribute to continuous improvement in the partnership. ○ Documents and other programmatic materials are shared on an ad hoc basis.
Transformative	○ Communication methods that encourage active-listening are in place and prioritized; partners feel empowered to voice issues, share ideas, and initiate dialogue. ○ Final products and documents have shared authorship and are exchanged on a regular basis. ○ A system for ongoing documentation (through two or more media) is in place and is actively used to communicate the value of the partnership / project through grant applications and reports, website and social media, newsletters, etc.

Table 7.1: Qualitative Self-Evaluation Rubric

8 Cumulative Benefit

As Sections 3, 4, 5, 6, and 7 presented, the subject matter expert review teams divided the strategic goals into a number of strategic objectives, and determined the weight of each strategic objective within its strategic goal. Table 8.1 summarizes the results.

Strategic Goal	*Strategic Objective*	*Objective Weight*
Safety and Health	User Safety	40%
	Worker Safety	20%
	Overall Health	40%
Stewardship and Efficiency	Asset Condition	50%
	Traffic Volume	30%
	Funding Source	20%
Sustainability, Livability, and Economy	People	30%
	Planet	40%
	Prosperity	30%
System Performance	Delay Reduction	25%
	Reliability	25%
	Integration and Corridor Management	25%
	Complete Streets	25%
Organizational Excellence	Employee Engagement and Innovation	10%
	Collaborative Partnerships	30%
	Skilled Communication	30%
	Effective Decision Making through Risk Management	30%

Table 8.1: Strategic Goals and Objectives

Sections 3, 4, 5, 6, and 7 also present a methodology to calculate a project's score toward each strategic objective. For each strategic goal, a weighted average equation then uses the objective weights from Table 8.1 to combine the objective scores into a goal score.

Note: The raw and normalized scores of the 37 nominated projects under the 2016 SHOPP Asset Management Pilot Program are presented in Appendix B. The normalized scores are the ratio of the raw scores to the maximum score of the corresponding strategic goal.

$$(Normalized\ S_i)_{Project\ n} = \frac{(Raw\ S_i)_{Project\ n}}{Max\left[(Raw\ S_i)_{Project\ n}\right]_{n=1}^{37}} \qquad i = 1, 2, \dots, 5 \tag{8.1}$$

The last step is to combine the goal scores into a single cumulative benefit. A linear additive model is used for this purpose.

8.1 The Linear Additive Model

A linear additive model [8] is used to combine the five goal scores into a single cumulative benefit. In the linear additive model, it should be possible to reasonably assume that strategic goals are independent form each other. It might be argued that some strategic goals in the Caltrans Strategic Management Plan 2015-2020 overlap; therefore, the assumption of goals independence is violated. First, the subject matter expert review teams independently score a project, and a goal score does not have any effect on another

goal score. Second, in cases such as active transportation where an overlap between Goal 1 and Goal 4 is suspected, different aspects of active transportation are evaluated. In other words, there is no overlap between the contributions of active transportation toward Overall Health (Goal 1) and toward Complete Streets (Goal 4). The linear additive model calculates the cumulative benefit through the following equations:

$$Benefit = \sum_{i=1}^{5} Goal\ Benefit_i$$

$$Goal\ Benefit_i = w_i * M_i * S_i \qquad i = 1, 2, \dots, 5 \tag{8.2}$$

In Equations (8.2), w_i is the goal weight of the i-th goal, M_i is the magnitude factor of the i-th goal, and S_i is the goal score of the i-th goal. A goal score is calculated via a weighted average equation which uses the weights and the scores of the goal's underlying objectives, and it was thoroughly explained in previous sections. The goal weights are determined through the Analytic Hierarchy Process (AHP) which will be explained in Section 8.2. The magnitude factors and the alternative ways to apply the magnitude factors will be explained in Section 8.3.

8.2 The Analytic Hierarchy Process

In the field of operations research, there are a variety of methods to determine the weights of objective functions (strategic goals).

Figure 8.1: AHP Pairwise Comparisons

One of these methods is the Analytic Hierarchy Process (AHP) [8]. Although the AHP has a number of challenges [9], it was deemed to be the most practical for the determination of the goal weights in the Project Prioritization Criteria 2016.

The AHP starts with 10 pairwise comparisons between any pair of the 5 strategic goals as it is illustrated in Figure 8.1. In this process, the members of the Department's Executive Board were asked to choose a comparative phrase from the 7 comparative phrases in the middle column of Table 8.2. These choices represent the participants' views on the relative importance of the strategic goals as defined by the subject matter expert review teams.

1. Goal 1 is	(i) very strongly more important than? (ii) strongly more important than? (iii) moderately more important than? (iv) equally important to? (v) moderately less important than? (vi) strongly less important than? (vii) very strongly less important than?	Goal 2.
2. Goal 1 is		Goal 3.
3. Goal 1 is		Goal 4.
4. Goal 1 is		Goal 5.
5. Goal 2 is		Goal 3.
6. Goal 2 is		Goal 4.
7. Goal 2 is		Goal 5.
8. Goal 3 is		Goal 4.
9. Goal 3 is		Goal 5.
10. Goal 4 is		Goal 5.

Table 8.2: Relative Importance of Strategic Goals

The comparative phrases of Table 8.2 are translated to numerical values in accordance with Table 8.3. The AHP uses these numerical values to calculate a participant's goal weights.

very strongly more important	7 times more important
strongly more important	5 times more important
moderately more important	3 times more important
equally important	1 time more important
moderately less important	1/3 times more important
strongly less important	1/5 times more important
very strongly less important	1/7 times more important

Table 8.3: Intensity of Importance

The details of the AHP calculations are explained in a number of references [9], and it is not necessary to repeat in the present document. The process was used to determine the goal weights from the responses of 16 members of the Department's Executive Board. The results in percentage (%) are illustrated in Figure 8.2, in which dots represent individual weights and dashes represent arithmetic means.

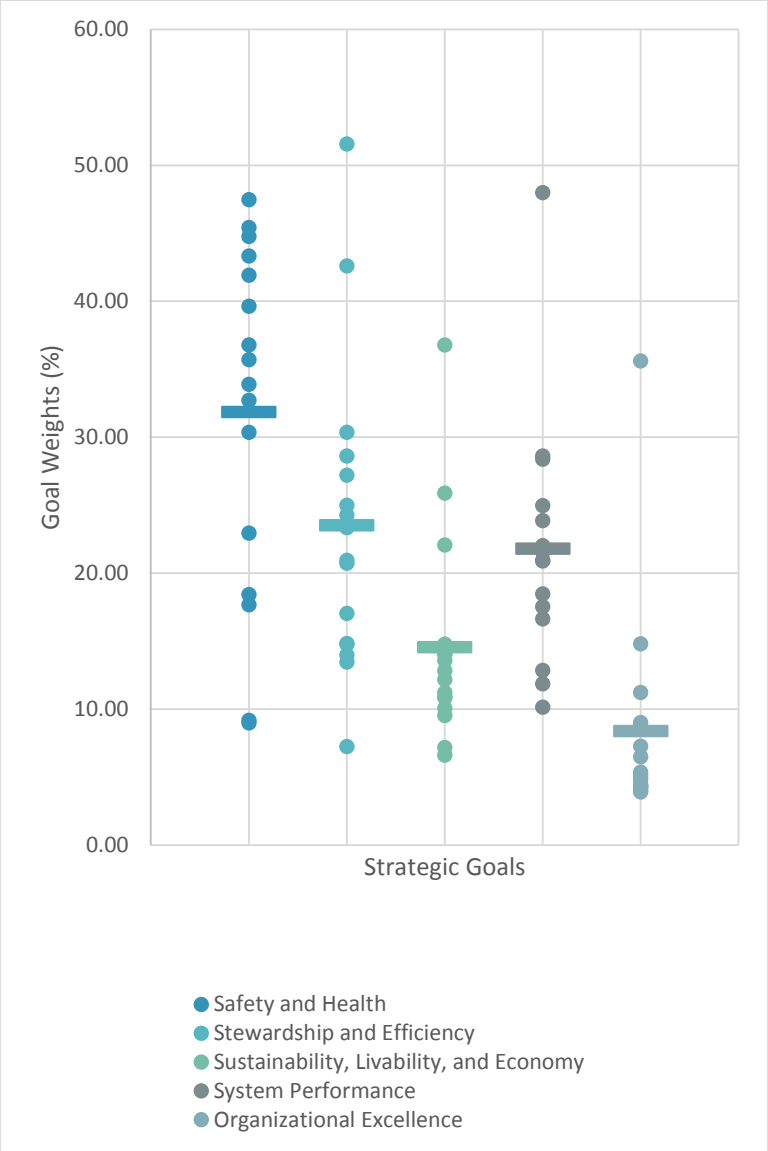

Figure 8.2: Goal Weights by the Department's Executive Board

The statistical measures of the 16 individual responses are summarized in Table 8.4.

	Goal 1	*Goal 2*	*Goal 3*	*Goal 4*	*Goal 5*
Mean	31.83	23.50	14.53	21.78	8.36
Median	34.81	22.15	12.49	21.26	5.23
Standard Deviation	12.73	11.27	7.71	8.80	7.88
Minimum	9.00	7.25	6.61	10.15	3.92
Maximum	47.46	51.56	36.79	48.00	35.61

Table 8.4: Statistical Measures of Goal Weights

As a result of this analysis, the average goal weights of Table 8.5, rounded to whole percentages, were selected for the Project Prioritization Criteria 2016.

Strategic Goal	*Goal Weight*
Goal 1: Safety and Health	32%
Goal 2: Stewardship and Efficiency	23%
Goal 3: Sustainability, Livability, and Economy	15%
Goal 4: System Performance	22%
Goal 5: Organizational Excellence	8%

Table 8.5: Goal Weights

The global objective weights are the product of the goal weights from Table 8.5 and the objective weights from Table 8.1. The global objective weights are presented in Table 8.6 although they are not explicitly used in Equations (8.2).

Strategic Objective	*Global Objective Weight*
User Safety	12.8%
Worker Safety	6.4%
Overall Health	12.8%
Asset Condition	11.5%
Traffic Volume	6.9%
Funding Source	4.6%
People	4.5%
Planet	6.0%
Prosperity	4.5%
Delay Reduction	5.5%
Reliability	5.5%
Integration and Corridor Management	5.5%
Complete Streets	5.5%
Employee Engagement and Innovation	0.8%
Collaborative Partnerships	2.4%
Skilled Communication	2.4%
Effective Decision Making through Risk Management	2.4%

Table 8.6: Global Objective Weights

The goal weights $w_1, w_2, \dots, w_5$ which are explicitly used in Equations (8.2) are the goal weights which are presented in Table 8.5.

8.3 The Magnitude Factors

The magnitude factors $M_1, M_2, \dots, M_5$ are introduced to reflect the magnitude of the improvements resulting from a project. The magnitude factors adjust the goal benefits to reflect the varying units of the activities involved in the project and the extent of the system improved by the project.

For example, two similar projects add shoulder rumble strips to pavement assets, but the length of the improvements for one project is greater than the other project. As a result, although they both share the same safety improvement benefit, the first project should receive a higher credit, i.e. a higher magnitude factor, for its enhancement over the greater length. This factor, in theory, allows the two projects to be equitably treated from a benefit-cost standpoint.

Three alternatives to determine the magnitude factors were initially explored:

1. No magnitude factor
2. A single magnitude factor M across all goal benefits
3. Multiple magnitude factors $M_1, M_2, \dots, M_5$, each of which corresponds to a strategic goal

8.3.1 No Magnitude Factor

This alternative is blind to asset values. In other words, a project gets the same credit for an enhancement over a lower value asset or over a higher value asset. Since a project which enhances a lower value asset generally has a lower cost, it will win the benefit-cost analysis over a higher cost project. As a result, the Department's portfolio will overwhelmingly include low-cost projects.

If the magnitude factors are eliminated from Equations (8.2), a project's cumulative benefit will be

$$Benefit = \sum_{i=1}^{5} w_i * S_i \tag{8.3}$$

The No Magnitude Factor assumption was applied to the 37 nominated projects under the 2016 SHOPP Asset Management Pilot Program. Equation (8.3) calculated the projects' cumulative benefits. The benefits were then divided by the projects' total SHOPP costs. The benefit to cost ratios were used to rank the projects. The results are presented in Appendix C. As predicted, the low-cost projects receive better ranks even though they have low cumulative benefits. As a result, the No Magnitude Factor alternative was deemed to be inappropriate for the project prioritization process.

8.3.2 Single Magnitude Factor

As the analysis of the previous section indicated, the project prioritization process should magnify a project's goal benefits on the basis of the monetary values of assets which are enhanced by the project's activities. It was therefore necessary to identify the assets which the project enhances, and estimate the values of the identified assets. These asset values are used to calculate the single project magnitude factor:

$$M = \frac{(AV)_{Project\ n}}{Min\left[(AV)_{Project\ n}\right]_{n=1}^{N}} \tag{8.4}$$

In Equation (8.4), $(AV)_{Project\ n}$ is the total value of all assets which are enhanced by the n-th project, and N is the number of nominated projects for the project prioritization process. The single magnitude factor reduces Equations (8.2) to

$$Benefit = \sum_{i=1}^{5} Goal\ Benefit_i$$

$$Goal\ Benefit_i = w_i * M * S_i \qquad i = 1, 2, \dots, 5 \tag{8.5}$$

The Single Magnitude Factor assumption was applied to the 37 nominated projects ($N = 37$) under the 2016 SHOPP Asset Management Pilot Program. The total value of all assets which were enhanced by each project was estimated. Equation (8.4) calculated each project's magnitude factor. Equations (8.5) used each project's magnitude factor to magnify the goal benefits and to calculate the project's cumulative benefit. The cumulative benefit was then divided by the project's total SHOPP cost. The benefit to cost ratios were used to rank the projects. The results are presented in Appendix D.

Unlike the No Magnitude Factor alternative, low-cost projects do not necessarily receive better ranks with the Single Magnitude Factor assumption. However, there is still a source of inaccuracy with a single magnitude factor across all goal benefits. For example, there is a high-value asset in the vicinity of a project. The project expands its limits to include the high-value asset and proposes a low-cost safety enhancement to the high-value asset. Since the value of the asset is high, it significantly increases the magnitude factor. The high magnitude factor magnifies all the goal benefits even though the high-value asset is only associated with the Safety and Health strategic goal. Since all the goal benefits are magnified by the single project magnitude factor, the project's cumulative benefit is increased because of a low-cost safety enhancement. As a result, the benefit to cost ratio increases, and the project receives a better rank, and this distorts the project prioritization process.

8.3.3 Multiple Magnitude Factors

The Single Magnitude Factor alternative is more accurate than the No Magnitude Factor alternative. However, it still has a source of inaccuracy as it was mentioned in the previous section. A project includes a variety of activities, but the activities do not necessarily enhance the project's assets with respect to all the strategic goals. Appendix E identifies 54 activities in a typical project. If an activity which is associated with the i-th strategic goal enhances a project's asset, the value of the mentioned asset should only magnify the i-th goal benefit. In other words, there should be multiple magnitude factors, one for each goal, and the value of the mentioned asset should only contribute to the calculation of the i-th magnitude factor. As a result, the magnitude factors should be calculated by

$$M_i = \frac{\sum_j AV_{j,i}}{Total\ SHOPP\ Cost} * 1{,}000 \qquad i = 1, 2, \dots, 4$$

$$M_5 = 1 \tag{8.6}$$

In Equations (8.6), $\sum_j AV_{j,i}$ is the sum of the values of all assets which are enhanced by any activity associated with the i-th strategic goal, and the total SHOPP cost is used to normalize the magnitude factors. The activities of a project are not typically associated with the Organizational Excellence goal; therefore, a unit magnitude factor is chosen for this strategic goal.

The Multiple Magnitude Factor alternative, Equations (8.2) and (8.6), was deemed to be the most comprehensive among the three alternatives for the project prioritization process. It was applied to the 37 nominated projects under the 2016 SHOPP Asset Management Pilot Program. First, the values of all assets which were enhanced by an activity in Appendix E were estimated. Then, the sums of the values of all assets which were enhanced with respect to a strategic goal were estimated. Equations (8.6) calculated each project's magnitude factors. The results are presented in Appendix F. Equations (8.2) calculated each project's cumulative benefit. The cumulative benefit was then divided by the project's total SHOPP cost. The benefit to cost ratios were used to rank the projects. The results are presented in Appendix G.

As it was implied in Section 8, a project's cumulative benefit is not enough to rank the project. The cumulative benefit per unit cost of a project determines its rank. Section 9 has a discussion on the benefit-cost analysis.

9 Benefit-Cost Analysis

Section 8 presented how a project's cumulative benefit is determined in the Project Prioritization Criteria 2016. Section 9 concludes the project prioritization process by a discussion on how the projects are ranked on the basis of both their cumulative benefits and their costs.

A project with a higher cumulative benefit should not necessarily rank higher than a project with a lower cumulative benefit. A higher cumulative benefit is desirable if it comes at a lower cost. The project prioritization process should analyze projects on the basis of both their cumulative benefits and their costs. In other words, a project with a higher cumulative benefit to cost ratio should rank higher than a project with a lower cumulative benefit to cost ratio. It is this ratio which should be used to rank projects. Using this approach, the projects with the greatest value to cost ratio are selected.

It is encouraged for projects to use partnered funds as it was mentioned in Section 4.4. If a project receives funds from other sources in addition to the SHOPP, the total project cost is not equal to the total SHOPP cost. The benefit-cost analysis therefore has two options:

1. $B/C = \frac{Benefit}{Total\ Project\ Cost}$
2. $B/C = \frac{Benefit}{Total\ SHOPP\ Cost}$

If the project receives funds in addition to the SHOPP, the sources of these funds could be other agencies with other strategic goals. The purpose of the Project Prioritization Criteria 2016 is to maximize the cumulative benefit to cost ratio for the SHOPP. Therefore, the second option is deemed to fulfill this purpose.

In summary, the Project Prioritization Criteria 2016 recommend to maximize the cumulative benefit to cost ratio for a project. A project with a higher value of the B/C ratio has a better chance to rank higher in the Department's project portfolio. This project prioritization process depends on the accomplishments of each project relative to its cost. This approach provides repeatable and objective criteria for project prioritization that is performance-based and considers the value for dollar of each transportation project across all assets and objectives. This prioritization process has shown to have merit and will allow the department to shift from silo-based management to a process that evaluates the comprehensive benefit to cost ratio for each project.

10 Future Needs

The completion of the 2016 SHOPP Asset Management Pilot Program marks a significant step toward the overall implementation of Transportation Asset Management. This pilot resulted in significant accomplishments that include a documented project evaluation criteria, alignment with the Caltrans Strategic Management Plan 2015-2020, a formal benefit-cost methodology for the SHOPP, initial weights for each of the Strategic Plan goals, and a shift in the cultural approach to project planning.

The Pilot Program also highlighted several areas for further study and refinement in the approach. Caltrans is not currently capturing the necessary data in the planning process that will allow prioritization to be conducted. The Pilot Program identified numerous data items that will need to be incorporated into future planning documents. There is need for additional analysis and external review of the objective functions and underlying data to determine if the prioritization criteria and weights are equitably treating all transportation system needs. For example, are the rural project locations being treated fairly in the analysis? Are the goal weights appropriate given the range of data underlying each goal scores? Are the Strategic Plan objectives sufficiently independent of each other as defined for each goal? Is the project magnitude factor being appropriately applied across all assets and objectives? The Department has initiated a contract with an external MODA expert who will be tasked with evaluating the questions noted above.

There are other considerations that need to be evaluated. Federal law requires the incorporation of risk management, life-cycle cost analysis, and performance management within the context of the Transportation Asset Management Plan (TAMP). The relationship between this project prioritization methodology and these other requirements needs to be evaluated. For example, it could be possible that the project prioritization methodology may not identify the appropriate project needed to achieve a condition performance objective identified under federal performance management requirements. The structure of the objective and sub-objective value functions used in the prioritization process needs to be aligned with the performance objectives to ensure that sufficient granularity exists within the weighting to address performance management objectives. These related asset management requirements will need to be evaluated and integrated into a single comprehensive asset management approach.

References

1. 112th Congress of the United States of America. Moving Ahead for Progress in the 21st Century Act.
2. 114th Congress of the United States of America. Fixing America's Surface Transportation Act
3. State of California Department of Transportation (2015) SHOPP Pilot Project; Phase 1: A Framework for Project Prioritization.
4. Crash Modification Factors Clearinghouse. http://www.cmfclearinghouse.org.
5. California Environmental Protection Agency (2014) California Communities Environmental Health Screening Tool, Version 2.0 (CalEnviroScreen 2.0); Guidance and Screening Tool.
6. State of California Department of Transportation Annual / Quarterly Mobility Performance Statistics. http://www.dot.ca.gov/hq/traffops/mpr/stats.html.
7. Pedestrian and Bicycle Safety Guide and Countermeasure Selection System. http://pedbikesafe.org/.
8. Department for Communities and Local Government: London (2009) Multi-Criteria Analysis: A Manual.
9. Triantaphyllou E, Mann SH (1995) Using the Analytic Hierarchy Process for Decision Making in Engineering Applications: Some Challenges. International Journal of Industrial Engineering, 2: 35-44.
10. State of California Department of Transportation (2015) The California Department of Transportation Strategic Management Plan 2015-2020.
11. State of California Department of Transportation (2012) Smart Mobility: A Survey of Current Practice and Related Research. Division of Research, Innovation, and System Information Preliminary Investigation.
12. State of California Department of Transportation (2013) Sustainability Tools and Practices: An Examination of Selected State Departments of Transportation, California Metropolitan Planning Organizations and National Tools. Division of Research, Innovation, and System Information Preliminary Investigation.
13. State of California. California Government Code § 14526.4.

Appendix A: Crash Modification Factors for Spot Locations and Systemic Safety

Countermeasure (s)	*Crash Type*	*Crash Severity*	*Area Type / Road Type*	*Daily Traffic Vol. (veh/day)*	*Crash Reduction Factor / Function (%)*	*Countermeasure Effectiveness*
ROADWAY DEPARTURE: BARRIER						
Improve guardrail	All	All		< 5000	18	D
	All	All		> 5000	9	E
	ROR	All			28	C
Install animal fencing	Animal	All	All		90	A
Install barrier (concrete) inside and outside curve	All	Fatal / Injury			39	B
Install guardrail (as shield for rocks and posts)	All	All			14	D
Install guardrail (as shield for trees)	All	Fatal			65	A
Install guardrail (at culvert)	All	All			27	C
Install guardrail (at ditch)	All	Injury			26	C
Install guardrail (at embankment)	ROR	Fatal			44	A
Install guardrail (inside curves)	All	Fatal / Injury			28	C
Install guardrail (outside curves)	All	Fatal / Injury			63	A
Install impact attenuators	All	All			29	C
Replace guardrail with a softer material (concrete→steel→wire)	ROR	Injury	All		32	B
ROADWAY DEPARTURE: BRIDGE						
Install bridge lighting	All	All			59	A
Install delineators (on bridges)	All	All			39	B
Install guardrail (at bridge)	All	All			24	C
Repair bridge deck	All	All			14	D
Replace bridge (general)	All	All	All		45	A

Upgrade bridge railing	All	All			20	C
Widen bridge	All	All			45	A
ROADWAY DEPARTURE: GEOMETRIC						
Flatten side slopes	All	All	All		30	B
Improve curve superelevation	All	All			40	A
Improve gore area	All	All			25	C
Improve horizontal and vertical alignments	All	All	All		50	A
Increase number of lanes	All	All		< 5000	20	C
	All	All		> 5000	31	B
Install acceleration / deceleration lanes	All	All			26	C
Install channelized lane	All	All			67	
Install passing / climbing lane	All	All	All		20	C
	All	Fatal / Injury	Rural / 2-lane		33	B
Install shoulder	All	All			9	E
Install truck escape ramp	All	All			18	D
Lengthen culverts	All	All			44	A
Narrow cross section (4 to 3 lanes with two way left-turn lane)	All	Urban	4-lane highway	8,000 - 17,400	37	B
Widen lanes	All	All			50	A
Widen shoulder (paved)	All	All			57	A
ROADWAY DEPARTURE: MEDIAN						
Install median barrier	All	All	All		86	A
Install median barrier (cable)	All	Injury	Multi-divided		29	C
Install median barrier (concrete)	All	Fatal			90	A
Install median barrier (steel)	All	Injury	Multi-divided		35	B
Install or upgrade median barrier near gore area	All	All			17	D
ROADWAY DEPARTURE: ROADSIDE						
Install snow fencing	Snow	All			53	A
Remove poles by burying utility lines	All	All			40	A
Remove or relocate fixed objects outside of clear zone	All	All	All		38	B
Widen clear zone (add 5 ft)	Fixed object	All			13	D
Widen clear zone (add 8 ft)	Fixed object	All			21	C
Widen clear zone (add 10 ft)	Fixed object	All			25	C
Widen clear zone (add 15 ft)	Fixed object	All			35	B
Widen clear zone (add 20 ft)	Fixed object	All			44	A
ROADWAY DEPARTURE: SIGNS						

Install chevron signs on horizontal curves	All	All			35	B
Install curve advance warning signs	All	All			30	B
Install curve advance warning signs (advisory speed)	All	All			29	C
Install delineators (general)	All	All			11	D
Install dynamic / variable accident warning signs	All	Injury	Freeways		44	A
Install dynamic / variable speed warning signs	All	All			46	A
Install guide signs (general)	All	All			15	D
Install guideposts or barrier reflectors	All	Fatal / Injury	Rural 2-lane		8	E
Install illuminated signs	All	All			15	D
Install pavement condition warning signs	All	All			5	E
Install post-mounted delineators (curves)	All	All			25	C
ROADWAY DEPARTURE: PAVEMENT						
Improve pavement friction (grooving)	All	All			21	C
Improve pavement friction (increase skid resistance)	Wet pavement	All	All		45	A
Improve pavement friction (overlay)	All	All		> 5000	13	D
				< 5000	20	C
Improve pavement friction (curve overlay)	All	All			17	D
Improve pavement friction (resurface with open-graded mix)	All	All			75	A
Install centerline rumble strips	All	All	Rural / 2-lane	5000 - 22000	14	D
Install shoulder rumble strips	All	All	Rural / multi-lane divided		16	D
	ROR	All	Rural / 2-lane		13	D
	ROR	All	Rural / Highway		27	C
	ROR	All	Freeway		18	D
Pave shoulder	All	All			15	D
ROADWAY DEPARTURE: MARKINGS						
Delineate multiple lanes (painted lane lines)	All	All	Urban / multi-lane		18	D
Install edgelines, centerlines and delineators	All	Injury	All		45	A
Prohibit on-street parking	All	All	Urban / Arterial	30000	42	A

ROADWAY DEPARTURE: LIGHTING						
Improve lighting	All	All	All		25	C
Install lighting at interchanges	All	All	All		50	A
ROADWAY DEPARTURE: OPERATION						
Add two-way left-turn lane	All	All	All		8	E
Convert from two-way to one-way traffic	All	All			43	A
Improve drainage patterns	All	All			32	B
Install sidewalk (to avoid walking along roadway)	Ped	All			74	A
PEDESTRIAN: SIGNALIZATION						
Add exclusive pedestrian phasing	Ped	All			34	B
Replace existing WALK / DON'T WALK signals with pedestrian countdown signal heads	Ped	Fatal / Injury	Urban (S.F.)		25	C
Install pedestrian signal	Ped	All			54	A
PEDESTRIAN: GEOMETRIC						
Convert unsignalized intersection to roundabout	Ped	F+I	Urban		27	C
Convert intersection to roundabout	Ped	All			89	A
Install pedestrian overpass / underpass	Ped	All			86	A
Install raised median (marked crosswalk) at unsignalized intersection	Ped	All			46	A
Install raised median (unmarked crosswalk) at unsignalized intersection	Ped	All			39	B
Install refuge islands	Ped	All			56	A
Install sidewalk (to avoid walking along roadway)	Ped	All			74	A
Install sidewalk (to avoid walking along roadway) (cont'd)	Ped	All			75	A
Narrow cross section (4 to 3 lanes with two way left-turn lane)	Ped	All	Urban		29	C
Provide paved shoulder (of at least 4 feet) (to avoid walking along roadway)	Ped	All			71	A
PEDESTRIAN: SIGNS / MARKINGS						
Add intersection lighting	Night	All			21	C
Add segment lighting	Night	All			20	C
Convert two-way to all-way STOP control	Ped	All			39	B

Improve lighting at intersections	Ped	Injury			42	A
INTERSECTION: SIGNAL OPERATIONS						
Install pedestrian signal	All	All			20	C
Provide protected left turn phase	All	All		< 5000	30	B
				> 5000	36	B
Convert signal from pedestal-mounted to mast arm	All	All			49	A
Install signals	All	All		< 5000	38	B
				> 5000	20	C
Install left-turn lane and add turn phase	All	All			58	A
Install right-turn lane	All	All			25	C
Install flashing beacons as advance warning	All	All			25	C
INTERSECTION: GEOMETRIC						
Convert intersection to roundabout	All	All			48	A
Improve sight distance to intersection	All	Fatal			56	A
Install Median	All	All			27	C
Provide bicycle box (advance stop bar to leave dedicated space for cyclists)	Bicycle	All			35	B
Provide Bike Lanes	Bicycle	All			36	B
Prohibit left-turns	All	All			45	A
Prohibit right-turn-on red					23	C

Crash Reduction Factor (%)	*Countermeasure Effectiveness*
0 - 9	'E'
10 - 19	'D'
20 - 29	'C'
30 - 39	'B'
40+	'A'

Appendix B: Raw and Normalized Scores of the Nominated Projects

Project Number	*District*	*County*	*Route*	*Raw*					*Normalized*				
				S_1	S_2	S_3	S_4	S_5	S_1	S_2	S_3	S_4	S_5
1	1	Mendocino	1	56	2	25	17	10	66	5	60	22	20
2	1	Humboldt	101	23	11	27	18	0	28	29	64	23	0
3	1	Humboldt	101	32	3	23	26	5	39	8	55	34	10
4	2	Plumas	70	43	1	20	21	10	51	4	48	27	20
5	2	Tehama	36	38	5	18	17	10	45	13	43	22	20
6	2	Shasta	151	39	9	17	11	10	46	24	40	14	20
7	3	Yuba	70	37	6	22	12	35	44	16	52	15	70
8	3	Butte	162	44	5	17	31	45	53	14	40	40	90
9	3	Nevada	49	31	4	16	26	30	37	11	38	34	60
10-A	3	Sutter	20 & 99	46	9	20	21	35	55	24	48	27	70
10-B	3	Sutter	20 & 99	46	9	20	21	35	55	24	48	27	70
11	3	Butte	99	52	3	19	15	30	62	9	45	19	60
12	3	Sutter	99	43	6	31	33	35	51	17	74	42	70
13	3	Sacramento	99	54	5	19	18	35	64	13	45	24	70
14	4	Santa Clara	82	52	7	17	13	5	62	17	40	16	10
15	4	Alameda	980	0	7	0	50	0	0	18	0	65	0
16	4	San Mateo	280	12	38	7	0	0	14	100	17	0	0
17	4	Alameda	185	38	10	11	7	5	45	25	26	9	10
18	5	San Luis Obispo	46	20	2	20	13	0	23	6	48	17	0
19	5	Santa Barbara	135	39	4	33	10	35	47	10	79	13	70
20	5	Monterey	183	35	13	35	26	0	42	34	83	33	0
21	6	Tulare	216	84	8	18	18	0	100	21	43	23	0
22	6	Fresno	269	69	3	24	23	0	82	7	57	31	0
23	7	Los Angeles	91	52	9	2	56	0	62	23	5	73	0
24	7	Los Angeles	110	34	6	4	68	0	41	14	10	88	0
25	7	Los Angeles	5	35	7	10	68	0	42	18	24	88	0
26	7	Los Angeles	5	24	4	14	1	0	29	12	33	1	0
27	8	Riverside	74	53	10	40	34	10	63	27	95	44	20

28	8	San Bernardino	18	70	7	42	20	10	84	17	100	25	20
29	8	San Bernardino	395	60	7	13	21	0	72	18	31	28	0
30	9	Inyo	395	43	6	20	17	15	51	16	48	22	30
31	10	Calaveras	4	30	8	10	3	10	36	21	24	3	20
32	11	San Diego	5	29	8	16	77	0	34	20	38	100	0
33	11	San Diego	56	34	3	14	23	20	40	9	33	29	40
34	11	San Diego	75	47	10	16	12	0	56	26	38	16	0
35	12	Orange	5	0	6	7	60	35	0	16	17	78	70
36	5	Madera	99	49	5	20	27	15	59	13	48	35	30
37	7	Los Angeles	1	62	3	32	38	50	73	8	76	49	100

Appendix C: Ranks of the Nominated Projects under No Magnitude Factor Assumption

Project Number	*Total SHOPP Cost* $* 10^{-3}$	*Benefit*	*B/C* $* 10^{6}$	*Rank*
32	$5,625	43	7.69	1
22	$7,595	43	5.68	2
26	$3,620	17	4.70	3
36	$9,500	39	4.11	4
15	$4,794	19	3.88	5
21	$13,391	48	3.62	6
30	$9,568	34	3.57	7
34	$9,955	33	3.34	8
17	$9,062	27	2.97	9
29	$12,900	38	2.92	10
20	$14,100	41	2.92	11
27	$19,000	52	2.74	12
8	$15,460	42	2.72	13
28	$19,498	53	2.72	14
5	$12,787	30	2.36	15
12	$19,991	46	2.32	16
16	$13,905	30	2.16	17
31	$10,325	22	2.15	18
13	$19,500	41	2.10	19
23	$20,000	42	2.10	20
25	$19,830	40	2.04	21
10-A	$20,545	42	2.03	22
33	$14,780	30	2.01	23
19	$18,701	37	2.00	24
3	$15,700	31	1.96	25
11	$19,220	38	1.96	26
14	$18,070	34	1.90	27
9	$17,285	32	1.87	28
24	$20,000	37	1.86	29
1	$23,000	38	1.64	30
4	$20,840	32	1.53	31
35	$22,600	29	1.28	32
10-B	$36,715	42	1.14	33
6	$35,900	31	0.86	34
7	$39,960	34	0.86	35
2	$38,400	30	0.79	36
18	$25,200	20	0.78	37
37	$151,000	56	0.37	38

Appendix D: Ranks of the Nominated Projects under Single Magnitude Factor Assumption

Project Number	*Total SHOPP Cost* $* 10^{-3}$	*M*	*Benefit*	*B/C* $* 10^{6}$	*Rank*
27	$19,000	17.78	924	48.64	1
16	$13,905	21.22	638	45.90	2
10-A	$20,545	21.12	882	42.92	3
31	$10,325	16.51	366	35.43	4
21	$13,391	9.21	446	33.34	5
35	$22,600	23.52	681	30.13	6
20	$14,100	10.22	420	29.82	7
14	$18,070	15.50	532	29.41	8
29	$12,900	9.24	349	27.02	9
10-B	$36,715	21.12	882	24.01	10
23	$20,000	10.23	429	21.45	11
32	$5,625	2.51	108	19.27	12
2	$38,400	23.13	700	18.22	13
34	$9,955	5.09	169	16.99	14
28	$19,498	6.02	319	16.36	15
30	$9,568	4.41	151	15.74	16
12	$19,991	6.46	299	14.96	17
19	$18,701	7.41	277	14.82	18
25	$19,830	6.64	269	13.54	19
17	$9,062	3.78	102	11.25	20
1	$23,000	6.71	253	11.02	21
6	$35,900	12.00	372	10.37	22
26	$3,620	2.18	37	10.23	23
18	$25,200	13.02	258	10.22	24
5	$12,787	3.99	120	9.40	25
3	$15,700	4.34	134	8.52	26
4	$20,840	5.29	169	8.09	27
8	$15,460	2.90	122	7.89	28
11	$19,220	4.00	151	7.83	29
9	$17,285	4.12	134	7.72	30
13	$19,500	3.32	136	6.99	31
15	$4,794	1.78	33	6.88	32
36	$9,500	1.46	57	6.00	33
22	$7,595	1.00	43	5.68	34
24	$20,000	3.01	112	5.60	35
33	$14,780	2.37	70	4.76	36
7	$39,960	2.70	93	2.33	37
37	$151,000	2.68	149	0.99	38

Appendix E: Typical Project Activities

Activity	
Bridge Preservation	Side Slopes
Bridge Replacement	Vegetation Control (Guardrail)
Bridge Rail	Wetlands
Bridge Widening	Median Barrier
Pedestrian Overcrossing	Rumble Strips
Replace Culverts	ADA Curb Ramps
Fish Passage	Bike Lanes
Maintenance Building	Curb and Gutter
Equipment Shop	Curb Extensions and PPB
Lab	Driveways
TMC	Intersection Improvements
Office Buildings	Multi-Use Path
Pavement Rehab / Replace	Pedestrian Signals (APS, PCT, PHB)
Pavement Overlay (CAPM)	Sidewalks
Median Island Paving	Transit (Bus Stations)
Shoulder	Utility Undergrounding
Erosion Control	Blank-out / Radar Speed Signs
Guard Rail	Census Station
HMA Dike	Changeable Message Sign
Luminaires / Lighting	CCTV
Maintenance Vehicle Pullouts	Fiber Optic Communications
Planting and Irrigation	Loop Detection Station (16 Loop VDS)
Rest Stop (Solar)	Ramp Meter
Retaining Wall	Railroad Crossing Arms
Roadside Paving	Roundabout
Rock Slope Protection	Traffic Signals
R/W Fencing	Video Detection

Appendix F: Multiple Magnitude Factors of the Nominated Projects

Project Number	M_1	M_2	M_3	M_4
1	13.48	530.36	61.33	0.87
2	0.00	1249.38	1.30	0.52
3	0.00	0.00	37.55	536.31
4	9.64	512.74	0.00	4.70
5	61.49	538.93	0.00	47.24
6	8.60	675.53	10.15	0.00
7	0.00	140.39	0.00	0.00
8	0.00	309.83	15.31	64.04
9	3.18	478.68	0.01	13.54
10-A	29.45	1365.34	226.33	513.99
10-B	16.48	764.02	126.65	287.62
11	0.00	342.62	85.07	4.16
12	0.00	209.59	91.54	369.99
13	76.41	270.77	6.92	0.00
14	12.17	427.50	1342.23	0.00
15	0.00	0.00	0.00	769.09
16	5.75	3164.33	0.00	0.00
17	0.00	790.11	76.97	0.00
18	281.65	787.24	0.00	4.48
19	11.12	667.85	142.71	1.34
20	11.06	1123.76	344.89	25.82
21	7.47	267.34	806.74	347.53
22	0.00	56.96	94.80	121.73
23	0.00	537.00	0.00	525.65
24	21.92	0.00	0.00	290.93
25	0.00	0.00	0.00	695.99
26	1113.26	0.00	137.02	0.00
27	212.11	878.21	510.87	342.51
28	0.00	351.57	290.15	0.00
29	0.00	1314.12	32.56	141.09
30	0.00	600.18	209.21	147.24
31	68.37	3238.26	14.99	0.00
32	97.78	355.56	422.22	50.18
33	234.20	41.81	13.19	44.29
34	0.00	664.81	119.34	278.62
35	0.00	0.00	0.00	2161.73
36	16.00	201.68	101.89	0.00
37	9.13	0.00	21.58	6.12

Appendix G: Ranks of the Nominated Projects under Multiple Magnitude Factor Assumption

Project Number	*Total SHOPP Cost* $* 10^{-3}$	*Benefit*	*B/C* $* 10^{6}$	*Rank*
16	$13,905	72808	5236	1
26	$3,620	10869	3003	2
15	$4,794	11031	2301	3
35	$22,600	37206	1646	4
31	$10,325	16130	1562	5
32	$5,625	6227	1107	6
27	$19,000	20418	1075	7
20	$14,100	13517	959	8
25	$19,830	13493	680	9
21	$13,391	8521	636	10
10-A	$20,545	12722	619	11
34	$9,955	5681	571	12
23	$20,000	11326	566	13
14	$18,070	10104	559	14
17	$9,062	4927	544	15
29	$12,900	6353	492	16
30	$9,568	4383	458	17
28	$19,498	5798	297	18
24	$20,000	5923	296	19
3	$15,700	4365	278	20
12	$19,991	5302	265	21
33	$14,780	3461	234	22
22	$7,595	1754	231	23
2	$38,400	8381	218	24
5	$12,787	2670	209	25
10-B	$36,715	7121	194	26
19	$18,701	3336	178	27
36	$9,500	1653	174	28
18	$25,200	3248	129	29
13	$19,500	2404	123	30
6	$35,900	3920	109	31
8	$15,460	1687	109	32
9	$17,285	1391	80	33
11	$19,220	1330	69	34
1	$23,000	1440	63	35
4	$20,840	649	31	36
7	$39,960	531	13	37
37	$151,000	537	4	38

Appendix H: Complete Streets Tally Sheet

Facility Location / Purpose	*Countermeasure Treatment*	*Sub-Description*	*Count (Installed)*
Along Roadway	Sidewalk		1
	Walkway		1
	Roadway Surface Improvement		0
	Paved Shoulder		1
	Walking Environment	Street Furniture	0
		Trees	0
		Lighting	0
	Pavement friction		0
	Safety Edge		0
	Rumble strips and stripes		1
	High Friction Surfaces		0
	Installing New Guardrail		0
	Upgrading Guardrail end Terminals		0
	Crash Cushions		0
	Vertical Clearance		0
	Bridge Rail		1
	Sign Retro-Reflectivity		0
	Signs / Striping / Wayfinding Signage		0
	RR Xings Upgrade / Rails Perpendicular		0
	Gaps		0
	Connections		1
Along Roadway			6
Crossings	Curb Ramps		1
	Marked Crosswalks and Enhancements	Mid-Block Crossing	1
	Curb Extensions/Bulb-Out		0
	Crossing Islands		0
	Raised Pedestrian Crossings		0
	Lighting and Illumination		0
	Parking Restrictions		0
	Pedestrian / Bike Overpass / Underpass		0
	Automated Pedestrian / Bike Detection		0
	Leading Pedestrian Interval		0
	Advance Yield / Stop Lines		0
	Signs / Striping / Wayfinding Signage		0
Crossings			2
Transit	Transit Stop Improvements	Shelter	0
	Access to Transit	Bike Parking	0
	Bus Bulb-Outs		0
	Signage		0
Transit			0
Roadway Design	Bikeway Class I Path		1

	Bikeway Class II Bicycle Lanes		1
	Lane Narrowing		0
	Streetcar Track Treatments		0
	Sight Distance Improvements		0
	Lane Reduction (Road Diet)		0
	Driveway Improvements		0
	Raised Median Island / Diverter		1
	One-Way / Two-Way Street Conversions		0
	Improved Right-Turn Slip-Lane Design		0
	Curb / Gutter		0
Roadway Design			3
Intersection Design	Intersection Median Barriers		0
	Curb Radius Reduction		0
	Modify Skewed Intersections		0
	Left Turn Lane		1
	Interchanges		0
	Merge and Weave Area Redesign		0
	Turning Restrictions		0
	Intersection Markings / Signs		0
	Roundabout		0
Intersection Design			1
Traffic Calming	Chokers		0
	Chicanes		0
	Mini-Circles		0
	Visual Narrowing		0
	Speed Tables / Humps		0
	Traffic Diversion		0
	Gateways		0
	Landscaping		0
	Specific Paving Treatments		0
	Serpentine Design		0
	Speed Reduction		0
Traffic Calming			0
Signals and Signs	Traffic Signals	Enhancements	0
		Left Turn Phasing	0
		Advanced Stop Lines at Traffic Signals	0
		Right-Turn-on-Red Restriction	0
		Optimized Timing for Bicyclists	0
		Pavement Marking Improvements	0
		Bike-Activated Signal Detection	0
	Pedestrian Signals	Timing	0
		Push Buttons	0
		Pedestrian Hybrid Beacon	0
		Rectangular Rapid Flash Beacon	0
		Puffin Crossing	0
		Signing	0
Signals and Signs			0
Other	School Zone Improvement		0
	Pedestrian Safety at Railroad Crossing		0

	Maintenance Needs Identified & Plan		0
	Secure Bicycle Parking		0
	Multimodal Traffic Counts		0
	Identify Traffic Plan during Construction for Bikes and Peds		0
Other			0
Interstate / Freeways / Expressways	HDM Considerations for Sections Open to Bikes / Peds	Shoulder Widths	0
		Drainage Grates	0
		Expansion Joints	0
		Utility Access Covers on Shoulders	0
		Frequency and Spacing of Entrance / Exit Ramps	0
		Multiple-Lane Entrance / Exit Ramps	0
		Traffic Volumes on Entrance / Exit Ramps and on Lanes Merging into Exit Ramps	0
		Sight Distance at Entrance / Exit Ramps	0
		Freeway to Freeway Interchanges	0
		The Presence and Design of Rumble Strips	0
		Longitudinal Edges and Joints	0
		Separate Facility - Class I	0
	Additional Interstate Treatments	Parallel Local Route with Effective Facilities	0
		Pedestrian Overpasses / Underpasses	0
		Roadway Surface Improvements	0
		Sign Improvements for Bicyclists & Pedestrians	0
		Widen Shoulders	0
		On / Off Ramp Pavement Markings	0
		Bridge and Overpass Access	0
		Lighting Improvements	0
		Sign Improvements for Motorists, Bicyclists, & Pedestrians	0
Interstate / Freeways/ Expressways			0
Bonus	Adopted Plan(s) & Agency Approval		1 x 0.2
	Multi-functional Collaboration		0
	in Caltrans Doc (TCR, CSMP, PSR-PDS)		1 x 0.2
Bonus			2 x 0.2