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16. ABSTRACT

This research developed a robust set of quantitative performance metrics, measures, and methodologies to assess project alignment with the Climate Action Plan for Transportation Infrastructure (CAPTI). The literature review included documenting measures and metrics in published reports, peer-reviewed journals, textbooks, and presentations. Subsequently, a Caltrans System Investment Strategy (CSIS) Project Evaluation Tool was developed to evaluate projects by quantifying performance measures and metrics across eleven criteria as follows: Mode shift (active transportation, transit, and rail elements), Vehicle Miles Traveled (VMT), Zero Emission Charging & Fueling Infrastructure, Safety, Climate Adaptation and Resiliency, Natural Resources and Ecosystems, Infill Development, Freight Benefit - (Throughput, Velocity, and Reliability), Congestion Relief, Public Engagement, and Benefits to Disadvantaged Communities. The outcome of this research will allow for a data- and performance driven approach to project nomination and evaluation.

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Task 4169: Quantitative Performance Measures for the Caltrans System Investment Strategy

FINAL REPORT

Submission Date: December 13, 2023

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Contents

Introduction and Background

This research aims to develop a robust set of quantitative performance metrics, measures, and methodologies to assess project alignment with the Climate Action Plan for Transportation Infrastructure (CAPTI). The outcome of this research will allow for a data- and performance-driven approach to project nomination and evaluation.

The Caltrans System Investment Strategy (CSIS) is an action item (s4.1) in the Climate Action Plan for Transportation Infrastructure (CAPTI). S4.1 directs Caltrans to develop a new, data- and performance-driven approach in the CSIS to align project nominations for discretionary grants with the ten CAPTI Investment Framework.

Literature Review

Approach

The team prepared a comprehensive list of references for the literature review. The literature selected for review was gathered through online web searches and recommendations by the Caltrans Panel. The review included documenting measures and metrics in published reports, peer-reviewed journals, textbooks, and presentations.
The reports and publications identified and collected for review were divided into three categories as follows:

1. Reports from the National/Federal/Regional/Other nations.
2. Reports from various State/Local Agencies, and
3. Journals/Textbooks/Slide Presentations.

The number of these references reviewed across the three categories is noted in Table 1 below. An effort was made to include at least one literature review for each of the eleven criteria as noted in Table 1.

Table 1: Number of reports, journals, etc. reviewed.

Criteria	Reports		Peer-reviewed Journals, Textbooks, Presentations, etc.	Total number of reports, journals, etc. reviewed	Number of reports, journals, etc. used (in preparing Table 2)
	National/ Federal/Regional/Other nations	State/Local Agency			
Mode shift (active transportation, transit, and rail elements)	4	3	3	10	6
Vehicle Miles Travelled (VMT)	3	3	1	7	3
Zero Emission Charging & Fueling Infrastructure	2	2	2	6	2
Safety	4	3	1	8	3
Climate Adaptation and Resiliency	2	2	1	5	2
Natural Resources and Ecosystems	1	1	1	3	1
Infill Development	3	2	1	6	1
Freight Benefit - Throughput, Velocity, and Reliability	3	3	1	7	2
Congestion Relief	3	5	1	9	6
Public Engagement	4	2	2	2	2
Benefits to Disadvantaged Communities	2	1	2	5	2
Total	**31**	**27**	**16**	**68**	**30**

Summary of Findings

A summary of reviews of various online published reports, regulations, journals and presentations on quantifying performance measures is presented below:

1. It was found that most of the reports and journals reviewed indicated similarity in the use of quantified performance measures and metrics in practice by various agencies. A list of key measures and metrics used for the nine criteria have been summarized in detail in Appendix A.

2. While numerous studies and reports were available on performance measures and metrics for the studied criteria, those for the “Zero Emission Charging & Fueling Infrastructure” criterion were mainly from peer-reviewed journals. This could be due to relatively recent knowledge that has been gaining importance for implementation in research related to zero-emission vehicles and the infrastructure requirements for efficient charging.

3. ‘Safety’ and ‘Congestion Relief’ were the most widely accepted criterion for determining project selection across all State DOT reports reviewed. Henceforth, performance measures for these two criteria were several and supported by a gamut of data sources.

4. Local agencies (such as cities or communities) select performance measures for projects that address solutions to local transportation issues and challenges they face. Hence, the performance measures and metrics developed were very specific on Mode Shift, Safety, Infill Development and VMT criteria.

5. Literature available on quantifying performance measures for the Natural Resources and Ecosystems criterion was limited. The land consumption measure and associated metrics presented in Appendix A for this criterion have been mainly borrowed from the United States Environmental Protection Agency (EPA).

6. Reliability was a widely used measure for satisfying the ‘Freight benefit’ criterion.

7. Federal and State projects often require matching funds for project selection, and thus, cost match has frequently been used as an evaluation element in project nomination and selection.

Each of the measures and metrics were further reviewed for their alignment with the 10 CAPTI guiding principles ([1]):

CAP 1: Building towards an integrated, statewide rail and transit network
CAP 2: Investing in networks of safe and accessible bicycle and pedestrian infrastructure
CAP 3: Including investments in light, medium, and heavy-duty zero-emission-vehicle infrastructure
CAP 4: Strengthening our commitment to social and racial equity by reducing public health harms and maximizing benefits to disproportionately impacted disadvantaged communities

[1] Climate Action Plan for Transportation Infrastructure (CAPTI), accessed on Dec 11, 2023. https://calsta.ca.gov/subject-areas/climate-action-plan

CAP 5: Making safety improvements to reduce fatalities and severe injuries of all users towards zero
CAP 6: Assessing physical climate risk
CAP 7: Promoting projects that do not significantly increase passenger vehicle travel
CAP 8: Promoting compact infill development while protecting residents and businesses from displacement
CAP 9: Developing a zero-emission freight transportation system
CAP 10: Protecting natural and working land
Findings on the measures and metrics showed their alignment with at least one CAPTI guiding principle for almost all the criteria, except for Public Engagement and Congestion Relief. Detailed information on the CAPTI alignment of the nine criteria and the other findings on their measures and metrics that can be quantified is presented in Appendix A.

Methodology and Data Sources

Approach

In this section, methodologies, data sources, software packages (wherever applicable) and complexities involved in the process of project nomination and evaluation were researched. The research team reviewed the resources available to understand how project evaluation can be carried out for the eleven criteria. Subsequently, complexities were also reported across various domains in the project evaluation process. Details on measures and metrics commonly used, along with methodologies and data sources, for project nomination and evaluation can be found in the Appendix B of this report.

Summary of Findings

Key findings from this task have been highlighted below:

1. For each criterion used for project nomination and evaluation, various performance measure data are available at the Federal and the State-level.
2. Each criterion was investigated without the influence of other criteria for project nomination and evaluation.
3. Data availability are to be determined carefully - as the forecast data, although available, need not necessarily be sensitive to the project evaluated.
4. Researchers and practitioners deploy a travel demand model (TDM) to determine output using a simulation method to assess project impacts. TDM can be complex, needing multiple inputs such as network information and travel demand data to predict mode shifts, freight mode throughputs and congestion points – out of the eleven criteria being investigated.
5. Mode shift and Freight benefits can be the most complex criteria used for project evaluation.
6. Determining project impacts for other criteria, such as the i) Safety, ii) Natural resources and Ecosystems, iii) Infill development, iv) Public engagement, v) Benefits to Disadvantaged Communities criterion, can be carried out through other means that are simpler in method and application - as noted below:
   i) *Safety*: Eliminating crashes or fatalities are the direct project-specific benefits determined through crash data from repositories such as those provided by NHTSA (Federal), SWITRS (California) etc.
   ii) *Natural Resources and Ecosystems*: Information on an affected ecosystem from a project can be estimated and visualized using Geographical information system (GIS).
   iii) *Infill Development*: Various models, such as theoretical-driven ones by machine learning and software packages such as CUBE can predict land-use utilization and future changes and depend on data from historical impacts or experience gathered from other projects (having similar demographics) used as examples. Theoretical

models deploying machine learning can also be used to predict infill development tied to land-use changes.

iv) *Public engagement*: Projects can be evaluated based on a simple survey among affected residents before their execution or implementation.

v) *Benefits to Disadvantaged Communities*: GIS can be a very useful technique to understand and visualize where projects are needed and how their impacts can be felt across communities.

7. Thus, for a project to be nominated and evaluated based on the studied criteria for their data sources, methodology, applicable modes and geographic area, the following levels of complexities is usually expected as shown in Table 2 below:

Table 2: Complexities in project nomination and evaluation

Criteria	**Complexity Level of Project Nomination and Evaluation** (none, low, moderate, or high)	Justification
Mode shift (active transportation, transit, and rail elements)	**High**	Travel demand model (TDM) is often deployed
Vehicle Miles Travelled (VMT)	**Low to High**	Depends on the project's impact in a rural or urban setting
Zero Emission Charging & Fueling Infrastructure	**Low**	Optimization models can be readily deployed
Safety	**None**	A before-after analysis can yield project benefits
Climate Adaptation and Resiliency	**None to Moderate**	Resiliency analysis can make the process complex
Natural Resources and Ecosystems	**None**	Buffer analysis with the help of GIS software can be carried out
Infill Development	**Low to Moderate**	Existing tools are handy, but complexities can occur if mode shift, relocation or gentrification are considered
Freight Benefit - Throughput, Velocity, and Reliability	**High**	TDM is often deployed
Congestion Relief	**High**	TDM is often deployed
Public Engagement	**None**	If addressed appropriately as per recommended guidelines and practices
Benefits to Disadvantaged Communities	**None to Moderate**	Ample data sources availability and GIS helps visualize the project impacts

Various key measures and metrics, along with the methodologies for quantifying them for each criterion has been described below. Alignment of the measures/metrics with respect to the 10 CAPTI Guiding Principles ([2]) are also presented.

Project Nomination and Evaluation Methodology

State-of-the-practice: examples

Six example cases of best practices for transportation project evaluation are presented based on various reviewed and documented measures from State DOTs, MPOs, and project decision-making guidelines.

[2] Climate Action Plan for Transportation Infrastructure (CAPTI), accessed on Dec 11, 2023. https://calsta.ca.gov/subject-areas/climate-action-plan

Example 1: State of Victoria, Australia (VicRoads)

The project ratings are based on scores for performance for key evaluation questions (KEQs) for investments, namely ([3]):

- KEQ1 (Appropriateness)
- KEQ2 (Efficiency)
- KEQ3 (Effectiveness)
- KEQ4 (Unintended Outcomes)
- KEQ5 (Impact Sustainability)

KEQ1: Appropriateness

Strategic fit

Performance rating	Score	Performance descriptors
Excellent	5	Strong evidence to show that program/project aligned with Government strategies
Good	4	Good evidence to show that program/project aligned with Government strategies
Adequate (Business as usual)	3	Some evidence to show that program/project aligned with Government strategies
Poor	2	Program/project did not align with any Government strategies
Insufficient evidence	1	Evidence unavailable or of insufficient quality to determine performance

Planning and design

Performance rating	Score	Performance descriptors
Excellent	5	Strong evidence to show that program/project was planned and designed appropriately
Good	4	Good evidence to show that program/project was planned and designed appropriately
Adequate (Business as usual)	3	Some evidence to show that program/project was planned and designed appropriately
Poor	2	Program/project was not planned and designed appropriately
Insufficient evidence	1	Evidence unavailable or of insufficient quality to determine performance

Delivery

Performance rating	Score	Performance descriptors
Excellent	5	Strong evidence to show that program/project was delivered appropriately
Good	4	Good evidence to show that program/project was delivered appropriately
Adequate (Business as usual)	3	Some evidence to show that program/project was delived appropriately
Poor	2	Program/project was delivered appropriately
Insufficient evidence	1	Evidence unavailable or of insufficient quality to determine performance

KEQ2: Efficiency

Cost efficiency

Performance rating	Score	Performance descriptors
Excellent	5	Significantly more cost-efficient when compared with similar projects
Good	4	Slightly more cost-efficient when compared with similar projects
Adequate (Business as usual)	3	As cost-efficient as other similar projects
Poor	2	Not as cost-efficient as other similar projects
Insufficient evidence	1	Evidence unavailable or of insufficient quality to determine performance

Time efficiency

Performance rating	Score	Performance descriptors
Excellent	5	Significantly more time-efficient when compared with similar projects
Good	4	Slightly more time-efficient when compared with similar projects
Adequate (Business as usual)	3	As time-efficient as other similar projects
Poor	2	Not as time-efficient as other similar projects
Insufficient evidence	1	Evidence unavailable or of insufficient quality to determine performance

KEQ3: Effectiveness

Achievement of benefits

Performance rating	Score	Performance descriptors
Excellent	5	All benefits exceed target
Good	4	All benefits meet target

[3] VicRoads and Public Transport Victoria, accessed on May 22, 2023. https://www.vicroads.vic.gov.au/planning-and-projects/evaluating-investments

Adequate (Business as usual)	3	50% of benefits meet target, 50% of benefits below target
Poor	2	No benefits meet target
Insufficient evidence	1	Evidence unavailable or of insufficient quality to determine performance

Distribution of benefits

Performance rating	**Score**	**Performance descriptors**
Excellent	5	Distribution of benefits match the ILM exactly
Good	4	Distribution of benefits almost match the ILM
Adequate (Business as usual)	3	Distribution of benefits match the ILM fairly well
Poor	2	Distribution of benefits do not match ILM
Insufficient evidence	1	Evidence unavailable or of insufficient quality to determine performance

Attribution/contribution

Performance rating	**Score**	**Performance descriptors**
Excellent	5	Project has attributed to all benefits
Good	4	Project has attributed to at least 50% of the benefits
Adequate (Business as usual)	3	Project has contributed to all benefits
Poor	2	Project has not contributed or attributed to any benefits
Insufficient evidence	1	Evidence unavailable or of insufficient quality to determine performance

Management (of disbenefits and risks to benefits)

Performance rating	**Score**	**Performance descriptors**
Excellent	5	All disbenefits and risks to benefits were identified and managed
Good	4	Almost all disbenefits and risks to benefits were identified and managed
Adequate (Business as usual)	3	Some disbenefits and risks to benefits were identified and managed
Poor	2	Disbenefits and risks to benefits were not identified or managed
Insufficient evidence	1	Evidence unavailable or of insufficient quality to determine performance

Cost-effectiveness

Performance rating	**Score**	**Performance descriptors**
Excellent	5	Significantly more cost-effective when compared with similar projects
Good	4	Slightly more cost-effective when compared with similar projects
Adequate (Business as usual)	3	As cost-effective as other similar projects
Poor	2	Not as cost-effective when compared with similar projects
Insufficient evidence	1	Evidence unavailable or of insufficient quality to determine performance

KEQ4: Unintended Outcomes

Unintended benefits

Performance rating	**Score**	**Performance descriptors**
Excellent	5	[Evidence]
Good	4	[Evidence]
Adequate (Business as usual)	3	[Evidence]
Poor	2	[Evidence]
Insufficient evidence	1	Evidence unavailable or of insufficient quality to determine performance

Unintended disbenefits

Performance rating	**Score**	**Performance descriptors**
Excellent	5	No unintended disbenefits identified
Good	4	Less than three minor unintended disbenefits identified
Adequate (Business as usual)	3	More than three minor unintended disbenefits identified
Poor	2	One or more significant unintended disbenefit identified
Insufficient evidence	1	Evidence unavailable or of insufficient quality to determine performance

KEQ5: Impact Sustainability

Likely Impact Sustainability

Performance rating	**Score**	**Performance descriptors**
Excellent	5	Benefits likely to be sustained for the 5 or more years
Good	4	Benefits likely to be sustained for the next 3-4 years
Adequate (Business as usual)	3	Benefits likely to be sustained for the next 1-2 year
Poor	2	No further benefits to be had.
Insufficient evidence	1	Evidence unavailable or of insufficient quality to determine performance

In summary, the general ratings for key evaluation questions is carried out using scores shown in table 3 below. Table 4 presents the scores used exclusively for KEQ3 (Effectiveness).

Table 3: Example Rubric

Performance rating	**Score**	**Performance descriptors**
Excellent	5	Performance is clearly very strong or exemplary. Any gaps or weaknesses are not significant and are managed effectively.
Good	4	Performance is generally strong. No significant gaps or weaknesses, and less significant gaps or weaknesses are mostly managed effectively.
Adequate (Business as usual)	3	Performance is inconsistent. Some gaps or weaknesses. Meets minimum expectations/ requirements as far as can be determined.
Poor	2	Performance is unacceptably weak. Does not meet minimum expectations/requirements
Insufficient evidence	1	Evidence unavailable or of insufficient quality to determine performance

Table 4: Example Results Chart

Performance	**Score**	**Description**	**Results**
Fails to deliver benefits	0	Shows a disbenefit; the indicator shows a negative target value for the benefit measure	[Evidence]
Below target	1	Shows some positive benefit but the indicator is below the target value for the benefit measure	[Evidence]
Meets target	3	Shows a good positive benefit; the indicator is close to the target value for the benefit measure	[Evidence]
Exceeds target	5	Shows a strong positive benefit; the indicator is well above the target value for the benefit measure	[Evidence]

Example 2: SMART SCALE Project Evaluation Process – Framework VDOT

The Virginia Department of Transportation follows the SMART SCALE evaluation process by categorizing the project as illustrated through the sketch below.

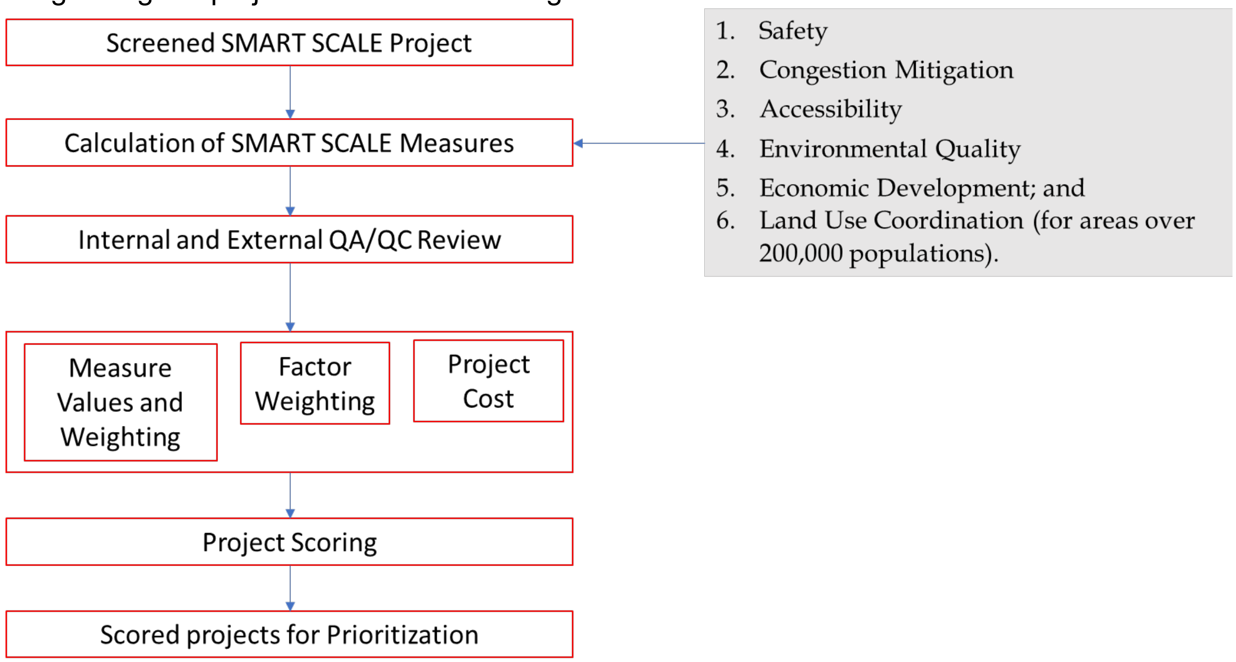


Figure 1: Framework for SMART SCALE Project evaluation

A project will receive a score or weighted based on diversity of transportation needs in different areas using category.

Table 5: Factor Weights by Category

Factor	**Congestion Mitigation**	**Economic Development**	**Accessibility**	**Safety**	**Environmental Quality**	**Land Use**
Category A	45%	5%	15%	5%	10%	20%
Category B	15%	20%	20%	20%	10%	15%
Category C	15%	25%	15%	25%	10%	10%
Category D	10%	30%	10%	30%	10%	10%

Example 3: Project Evaluation (Using Multiple Criteria Technique)

The third example study describes project evaluation and programming as recommended for transportation decision-making. The decision-making flowchart uses a multiple-criteria process, as illustrated in Figure 2 below ([4]).

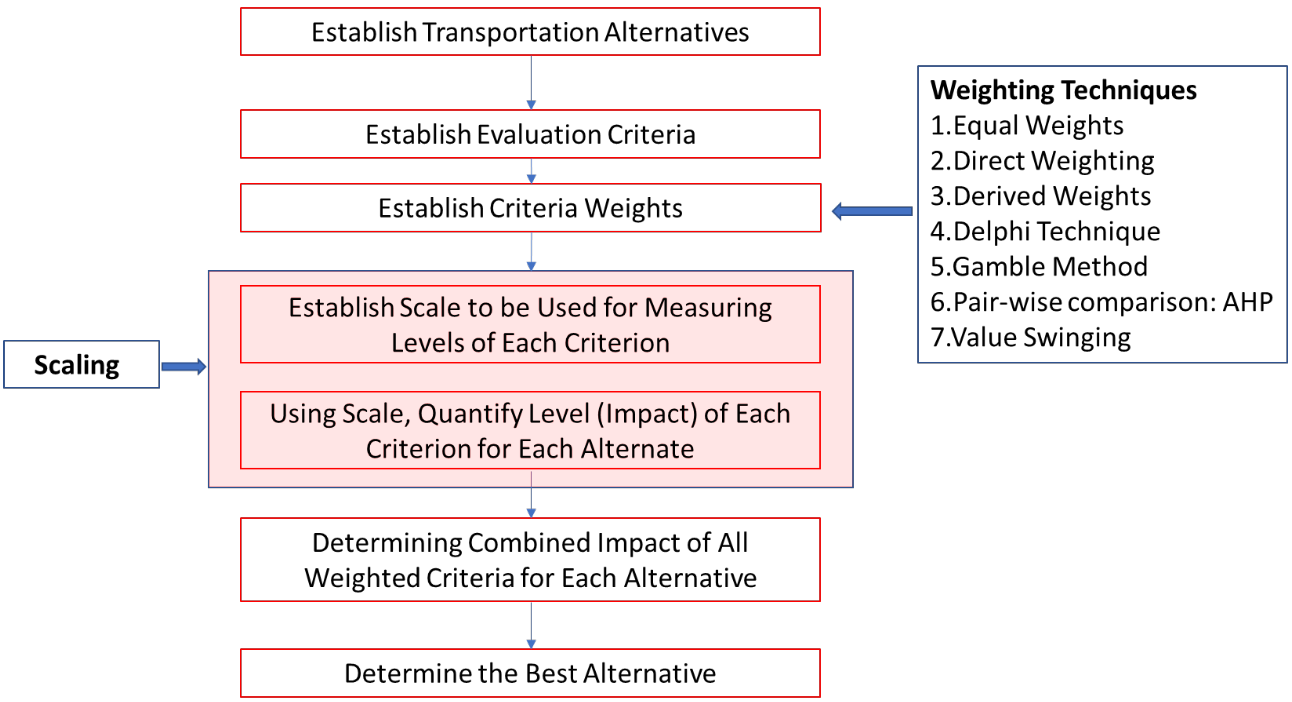


Figure 2: Multiple Criteria Technique

Example 4: Project Evaluation (TxDOT)

This example is from an MPO from Texas that follows the Texas Department of Transportation (TxDOT) project evaluation and selection criteria method ([5]). The procedure involves allocating points to various measures such as congestion, safety etc. Tables 6-8 provide examples of the scoring criteria used to rank and prioritize existing and new roadway facilities.

Table 6: Congestion (0 – 10 POINTS EACH, 30 TOTAL MAX)

Present LOS		**Evaluation Factor: Future LOS (No Build)**		**Change in Future LOS (Build vs. No Build)**	
A	-5 points	A	-5 points	No change in LOS	0 points
B	-3 points	B	-3 points		+5 points

[4] Sinha, K. C., & Labi, S. (2011). Transportation decision making: Principles of project evaluation and programming. John Wiley & Sons. (Slides) – a summary of methods that are similar to MCDM is explained.
[5] Mobility 2040, Killeen-Temple Metropolitan Planning Organization (MPO) - https://ktmpo.org/wp-content/uploads/2013/03/Appendix_B_Project-Selection-Process.pdf

C	0 points	C	0 points	LOS increase by 1 letter	
D & E	+5 points	D & E	+5 points	LOS increase by more than 1 letter	+10 points
F	+10 points	F	+10 points		

Table 7: Traffic (2-20 POINTS)

Proposed Roads		Existing Facilities		
			Existing ADT	Projected ADT
70,000 +	20 points	70,000 +	10 points	10 points
50,000 - 69,999	17 points	50,000 - 69,999	8.5 points	8.5 points
30,000 - 49,999	14 points	30,000 - 49,999	7 points	7 points
20,000 - 29,000	11 points	20,000 - 29,000	5.5 points	5.5 points
15,000 - 19,999	8 points	15,000 - 19,999	4 points	4 points
10,000 - 14, 999	5 points	10,000 - 14,999	2.5 points	2.5 points
< 10,000	2 points	< 10,000	1 point	1 point

For safety points assigned based on crash rate and alignment with design standards:

$$\textbf{Road Segment Accident Rate} = \frac{\text{Total \# of Accidents in 3 year period} \times 1{,}000{,}000}{365 \text{ (days/yr)} \times 3 \text{ (yrs)} \times \text{ADT} \times \text{Length of Road}}$$

Table 8: Safety (0 – 10 POINTS, 0-1 POINTS, 15 TOTAL MAX)

Design Type	Yes	No
Horizontal Alignment	0 points	1 point
Vertical Alignment	0 points	1 point
Horizontal Clearance	0 points	1 point
Shoulder Width	0 points	1 point
Lane Width	0 points	1 point

Other considerations include the type of local priorities for the project and using the point-based system of assignment as shown below:

Local Priority (0 – 5 POINTS EACH, 20 TOTAL MAX)

- *Community Support (0-5 points)*
- *Peak Hour Traffic Flow (0-5 points)*
- *Statewide, MPO or Local Benefit (0-5 points)*
- *Connectivity and Circulation within the existing network (0-5 points)*

Finally, once projects are scored, all projects are ranked in order from highest to lowest score.

Example 5: Project Evaluation (DelDOT)

The fifth example of project evaluation is from the Delaware Department of Transportation (DelDOT)[6]. The process involves creating a level of importance for each of the criteria based on the mission, vision and goals of the department and the percentages are found below:

1. Safety – 35.0%
    - Crash Index (16.2%): The Crash Index of location is based on three (3) most recent calendar years of crash data.
      The crash index value CI = (Number of Fatal Crashes * 40) + (Number of Injury Crashes * 4.5) + (Number of Property Damage Only Crashes *1)
    - Critical Crash Ratio (12.7%). The critical crash ratio is a site selection methodology calculated by including three (3) years of fatal and injury crash data and comparing crash rates along
      each roadway against statewide averages of similar roadway types.
    - Addresses strategies in the Strategic Highway Safety Plan (6.1%). The project may address one or more of the strategies identified in the current Strategic Highway Safety Plan.

2. System Operating Effectiveness – 19.1%
    - Existing Congestion Level (12.4%)
    - Congestion Management (6.7%)
    - Multi-Modal Mobility/Flexibility/Access (11.9%)

3. Multi-Modal Mobility/Flexibility/Access: 11.9%
    - Create a significant improvement by positively impacting multiple groups or locations
    - Create a moderate improvement by positively impacting a single user group or location
    - Neither improve nor degrade the existing access and mobility within the project limits
    - Negatively impact the transportation choices or access/connectivity

4. Revenue Generation/Economic Development/Jobs & Commerce – 13.1%
    - Economic Impact (Competitiveness) (5.7%)
        - Percentage Change in Employment (2.85%) & Percentage Change in GDP (2.85%)
    - Identified in a Transportation Improvement District (TID) (3.2%)
    - Cost-sharing Support (1.6%)
    - Freight Corridor (2.6%)

5. Impact on the Public/Social Disruption/Economic Justice – 8.3%
    - Impact on the Public/Social Disruption (4.3%)
    - Social and Health Related Elements (4.0%)

6. Environmental Impact/Stewardship – 6.6%. The effect of the transportation system on energy use and the natural environment.

[6] Delaware Department of Transportation (DelDOT), accessed on May 20, 2023, https://deldot.gov/Publications/reports/CTP/pdfs/DelDOT_project_prioritization_criteria_summary.pdf

7. State and Local Priority – 6.1%
    - Delaware Strategies for State Policies and Spending (3.9%)
    - Local Priority (2.2%)
    -

Example 6: Project Prioritization (NCDOT)

Project prioritization by NCDOT involves weighting criteria (in any mode) to calculate a quantitative score and combining the score with the Local Input to create a project's total score ([7]).

Table 9: Quantitative Score vs. Local Input

Funding Category	Data	Local Input (Division, MPO/RPO)	
Statewide Mobility	Criteria 1 = 30%		
	Criteria 2 = 25%		
	Criteria 3 = 15%		
	Criteria 4 = 10%		
	Criteria 5 = 15%		
	Criteria 6 = 5%		
Regional Impact	Criteria 1 = 20%	15%	15%
	Criteria 2 = 20%		
	Criteria 3 = 10%		
	Criteria 4 = 10%		
	Criteria 5 = 10%		
Division Needs	Criteria 1 = 15%	25%	25%
	Criteria 2 = 15%		
	Criteria 3 = 10%		
	Criteria 4 = 5%		
	Criteria 5 = 5%		

The criteria mentioned above further involve assigning weights for the following:

1. Highway Criteria & Weights
2. Aviation Criteria & Weights
3. Bicycle/Pedestrian Criteria & Weights
4. Ferry Criteria & Weights
5. Public Transportation Criteria & Weights (Mobility Projects)
6. Rail Criteria & Weights

Summary of Findings

The key findings are summarized below based on the review of various methodologies agencies adopt for project nomination and evaluation.

1. Ranking a project often involves assigning weights, scores, or points for each performance measure under consideration.

[7] Prioritization 6.0 Scoring Criteria, Weights, and Normalization for All Modes, NCDOT, accessed on May 24, 2023, https://connect.ncdot.gov/projects/planning/MPORPODocuments/P6.0%20Scoring%20Overview%20for%20BOT%206-6-2019.pdf

2. Assigning weights or points to a measure is based on rules or guidelines used as a rubric or reference.

3. The set of quantified performance measures may not be exhaustive; often, only a select number of measures are prioritized in project nomination and evaluation.

4. Quantitative performance measures may not always be used. For example, a quantitative measure may be used with other qualitative criteria, such as the Level-of-Service (LOS), for project evaluation.

5. Weights for quantitative measures often involve weighing local inputs or needs. The magnitude of these weights from local inputs may be limited or nonexistent for a project impacting statewide performance.

Proposed Methodology

Key Remarks

In this study, quantitative metric scores for all criteria are developed such that each metric score varies between -1 to 1. This approach is based on the following findings:

i) Certain scales of metric evaluation require pre-determination of thresholds or lower/upper limits in metric values for a given criterion. These thresholds may not have scientific backing to justify evaluation of projects across multiple metrics for a criterion.
ii) With the use of score varying on a scale of -1 to 1, project evaluations become consistent with the metrics considered across all criteria.
iii) Having to use two or more scales for metric scores of multiple criteria could result in statistical bias among project's overall scores. For example, a scale of 1 to 5 for a metric X and a scale of -5 to 5 for a metric Y is inconsistent and could indicate statistically different outputs for the multiple projects evaluated, and finally,
iv) Interpretation of the final scores for criteria for the projects evaluated is made simple with use of a consistent scale -1 to 1 across all metrics.

The proposed methodology for scoring formula for the metrics for the eleven criteria is presented in detail in Appendix C. Here we provide a very general approach for the methodology, as follows:

Four key input parameters are considered for the formula of the metric score developed in this research. These parameters are:

1. Percentage improvement in quantified benefits assessed using appropriate metric
2. Population/potential users residing close to the project and impacted or benefited by the project
3. Project alignment with the funding program, and
4. Probability of the project yielding the expected metric value.

Thus, the formula for the metric score for a given criterion is expressed as:

$$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r \qquad (1)$$

where,
m = quantified metric which is expressed as *percentage improvement* (benefit) or *deterioration* compared to build scenario based on if a desirable increase or decrease in the metric value is expected.

Example:

- Future 'No-build' scenario metric value is X

- 'Build' scenario metric value is Y

Therefore,

- If an increase in the metric value for 'build' scenario is desirable, then *m* = (Y – X)/Y.
- If a decrease in the metric value for 'build' scenario is desirable, then *m* = (X – Y)/X.

$Pop_{0.25}$ = population residing and impacted within *quarter-mile* distance of the project
$Pop_{0.50}$ = population residing and impacted within *half-mile* distance of the project

Notes: The ratio, $\frac{Pop_{0.25}}{Pop_{0.50}}$, reflects the impact (benefits) of the project on population residing within a quarter-mile distance of the project when compared to those that live further away but within the half-mile distance of the project's vicinity. The population residing can also be understood to be the surrogate for actual users of the facility improved through the project. The ratio, $\frac{Pop_{0.25}}{Pop_{0.50}}$, will vary between 0 and 1 - where a 0 will indicate no person resides within the quarter-mile distance to the project, while 1 would indicate that all the population live within the quarter-mile distance to the project and none beyond that upto the half-mile distance. It is expected that a project will benefit those residing close to a project with its benefits decreasing with increased distance further away from the project. The ratio, $\frac{Pop_{0.25}}{Pop_{0.50}} = 0$, if both $Pop_{0.25}$ and $Pop_{0.50}$ are 0, unless otherwise specified for computing the metric score of a criterion.

D_{align} = alignment of the project with the funding program, where, 1 indicates alignment and 0 = indicates non-alignment
and,
P_r = probability of the project yielding the expected benefits or output in terms of the quantified metric. The assumption is deriving the probability values is that, with some approximation, the project costs and the resulting metrics vary linearly.

Note: Range for the score, S: -1 to 1

The probability, P_r, is derived as follows:

Assume that historical data on project costs and the quantified metric values are available - as per the information provided in Table 10 below. The information in Table 10 presents a linear variation between project cost and the metric value, which are assumed to be available from historically funded projects in the past. Thus, (*K*, *a*) and (*L*, *b*) are the two points on a straight line obtained using linear regression from historical data of investment (i.e. *K* and *L*) versus metrics (i.e. *a* and *b*). The project with cost *K* has a metric value of *a* and the project with cost *L* has a metric value of *b*.

Table 10: Matrix of project cost versus metric compiled from historical data

Regression-based Project Cost in $ (determined from historical data)	**Regression-based Mean Quantified Metric** (determined from historical data of past funded projects)	**Probability of project achieving the expected metric value**
K	*a*	
C	*V*	1
L	*b*	

Now assume that there is a project to be evaluated has a cost *C* greater than *K* but less than *L* (i.e. $K \leq C \leq L$) and with an expected output of a metric with quantified value *V* such that $a \leq V \leq b$. The probability of this project achieving the expected benefit (expressed through the quantified metric *V*) is $P_r = 1$.

Otherwise, for all other costs and expected metric values, the probability of a project achieving the expected metric output is determined using the formula:

$$P_r = \frac{\left|V - \left(\frac{(C-K)(L-K)}{(b-a)} + a\right)\right|}{V} \qquad (2)$$

As stated earlier, the formula in equation (2) is based on the linear variation in cost of project versus its metric outcome. The expression $\left|V - \left(\frac{(C-K)(L-K)}{(b-a)} + a\right)\right|$ gives the absolute value of the difference in proposed project metric value *V* and the expected metric value that should be $\left(\frac{(C-K)(L-K)}{(b-a)} + a\right)$.

It is noted that the metric score for a criterion presented in equation (1) varies between 0 and 1. In project evaluation if the historical data on project costs and metrics are not available the probability P_r can be assumed to be equal to 1.

In the next sections, a detailed definition for the metric score is shown for each of the 11 performance criteria.

Note: Range for the score, S: -1 to 1

Example

Consider three projects A, B and C for evaluation with metric data provided in Table 11.

Table 11: Percentage improvement or deterioration in quantified metrics (in terms of percentages)

Criteria	*Project A*	*Project B*	*Project C*
Mode shift	10%	2%	-4% (decrease in mode shift)
VMT	-5% (increase in VMT)	-2% (increase in VMT)	5% (decrease in VMT)
Improve safety	100%	0	100%

Assuming $\left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) = 0.5$, D_{align} = 1 and P_r = 1 for all the three projects, the score *S* is calculated and presented in Table 5.

Table 12: Metric score calculation

Criteria	*Project A*	*Project B*	*Project C*
Mode shift	$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r$ $S = 0.1 \times 0.5 \times 1 \times 1 = 0.05$	$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r$ $S = 0.02 \times 0.5 \times 1 \times 1 = 0.001$	$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r$ $S = -0.04 \times 0.5 \times 1 \times 1 = -0.002$
VMT	$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r$ $S = -0.05 \times 0.5 \times 1 \times 1 = -0.025$	$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r$ $S = -0.02 \times 0.5 \times 1 \times 1 = -0.001$	$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r$ $S = 0.05 \times 0.5 \times 1 \times 1 = 0.025$
Improve safety	$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r$ $S = 1 \times 0.5 \times 1 \times 1 = 0.5$	$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r$ $S = 0 \times 0.5 \times 1 \times 1 = 0$	$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r$ $S = 1 \times 0.5 \times 1 \times 1 = 0.5$

For criteria weights as determined using the Analytical Hierarchy Process (AHP) and assumed to be found to be equal for all the three projects, as presented in Table 13, the project scores are calculated (Table 14):

Table 13: Criteria weights

Criteria	*AHP determined Weights (assumed)*
Mode shift	0.19
VMT	0.11
Improve safety	0.62

Table 14: Project scores

Project	*Composite Score after evaluation*
Project A	0.05×0.19 + (-0.025)×0.11+ 0.5×0.62 = **0.31675**
Project B	0.001×0.19 + (-0.001)×0.11 + 0×0.62 = **0.00008**
Project C	(-0.002)×0.19 + 0.025×0.11 + 0.5×0.62 = **0.31237**

Appendix A

Summary of Quantifiable Performance Measures and Metrics

Criteria	Applicable Project Type (Highway Rail Active transportation (bicycle, pedestrian, etc.)	Performance Measure(s)	Metric(s)	Description (methodology, planning assumptions etc.)	Key Reference(s)	CAPTI Alignment (see CAP definitions under Literature Review section)
Mode shift (active transportation, transit, and rail elements)	Active transportation (bicycle, pedestrian, etc.)	Effectiveness of infrastructure interventions (in promoting walking and cycling for transport)	Distance from the infrastructure (a measure of potential usage), and actual usage of the infrastructure	The study supported the construction of walking and cycling routes, but also suggested that such infrastructure alone may not be enough to promote active travel.	Song et al. (2017)[8]	**CAP 2 and 7**
	Transit	Transit ridership/Passenger counts Total rider usage (passenger miles traveled)	Boardings recorded by public transit providers	Measures include those developed as part of the 20-year Statewide Multimodal Transportation Plan for states like Minnesota. RAISE Discretionary Grant: Count of the passenger boardings and alightings at stations within the project area.	MinnesotaGO dashboard ([9]) RAISE 2021 Discretionary Grant ([10])	**CAP 1 and 7**

[8] Song, Y., Preston, J., Ogilvie, D., & iConnect Consortium. (2017). New walking and cycling infrastructure and modal shift in the UK: A quasi-experimental panel study. Transportation research part A: policy and practice, 95, 320-333.
[9] Minnesota DOT, https://performance.minnesotago.org/
[10] Performance Measurement Guidance for the RAISE 2021 Discretionary Grant Program, USDOT, accessed on April 16, 2023, https://www.transportation.gov/sites/dot.gov/files/2022-06/RAISE%202021%20Interim%20Performance%20Measures%20Guidance.pdf

				Total rider usage (passenger miles traveled): Calculation of weekday passenger miles of travel for the segments of transit routes operating in the study area, based on the scheduled transit service and the directional transit passenger counts collected for a typical weekday. Transit agencies may collect data during the year by using drivers' logs, scheduling software, automatic passenger		
	Bicycle and Pedestrian	Bike and pedestrian counts	Difference between pre and post project counts	Collect pre-project ("baseline") and during-project ("outcomes") counts Other methods from RAISE Discretionary Grant include calculating the average daily bicycle and pedestrian counts using National Bicycle & Pedestrian Documentation Project methodology by conducting hourly counts at key locations in the study area. Counts will be collected on a typical weekday, Saturday and Sunday and should be conducted monthly to produce a quarterly average.	Sacramento Area Council of Governments ([11]) RAISE 2021 Discretionary Grant ([12])	**CAP 2 and 7**
	Complete street	Travel cost impacts Level of Traffic Stress (LTS) – to describe road conditions	Bike and walk travel costs were defined as zero. LTS is measured on an ordinal scale, usually from 1 to 4, with levels at the bottom of the scale	Compute elasticities and non-motorized mode shares.	Bas et al. (2023)[13]	**CAP 1, 2 and 7**

[11] Sacramento Area Council of Governments, accessed on May 21, 2023. https://www.sacog.org/sites/main/files/file-attachments/measuring_pilot_performance_sheet.pdf?1667422216

[12] Performance Measurement Guidance for the RAISE 2021 Discretionary Grant Program, USDOT, accessed on April 16, 2023, https://www.transportation.gov/sites/dot.gov/files/2022-06/RAISE%202021%20Interim%20Performance%20Measures%20Guidance.pdf

[13] Bas, J., Al-Khasawneh, M. B., Erdoğan, S., & Cirillo, C. (2023). How the design of Complete Streets affects mode choice: Understanding the behavioral responses to the level of traffic stress. Transportation Research Part A: Policy and Practice, 173, 103698.

		and network design.	corresponding to lower levels of stress.			
Vehicle Miles Travelled (VMT)	Automobiles and all street classifications	Change in Daily Vehicle Miles Travelled	"No Build"/ "Build" Change in VMT	The basic formula is: Vehicle Volume multiplied by Impacted Length of the Project in a "Build" Scenario minus Vehicle Volume multiplied by impacted Length of the Project in a "No Build" Scenario. RAISE Discretionary Grant: The hours (miles) that a vehicle is scheduled to or actually travels from the time it pulls out from its garage to go into revenue service to the time it pulls in from revenue service. It is often called platform time. Other methodologies used for calculating VMT are stated below: **Approach 1** - Using the Cal B/C Sketch Model Formula: (Build annual average vehicle volumes multiply by project length minus Vehicle Volume multiply by Impacted Length of the Project in a "No Build" Scenario) divided by 365 (days)	Senate Bill 1 - State of California State of California Transportation Commission, 2022([14]). Florida DOT Source Book Calculations Documentation ([15]) RAISE 2021 Discretionary Grant ([16]) Ewing and Hamidi (2014) ([17]) Noland (2001) ([18])	**CAP 7**

[14] State of California State of California Transportation Commission, Jan 2022, https://catc.ca.gov/-/media/ctc-media/documents/ctc-workshops/2022/sb-1/performance-measurement-guidebook-final-draft.pdf

[15] Florida DOT Source Book Calculations Documentation, accessed on May 21, 2023, https://www.fdot.gov/docs/default-source/planning/fto/mobility/Task4-Documentation.pdf

[16] Performance Measurement Guidance for the RAISE 2021 Discretionary Grant Program, USDOT, accessed on April 16, 2023, https://www.transportation.gov/sites/dot.gov/files/2022-06/RAISE%202021%20Interim%20Performance%20Measures%20Guidance.pdf

[17] Ewing, R., & Hamidi, S. (2014). Longitudinal analysis of transit's land use multiplier in Portland (OR). *Journal of the American Planning Association*, *80*(2), 123-137.

[18] Noland, R. B. (2001). Relationships between highway capacity and induced vehicle travel. Transportation Research Part A: Policy and Practice, 35(1), 47-72.

				Approach 2 - Using Caltrans' Highway Operations Average Annual Daily Traffic reports. Formula: Traffic Volumes multiply by Impacted Length of Freeway **Approach 3** - High Level Description of How One Larger Regional Transportation Planning Agency (the Sacramento Area Council of Governments) Calculates Change in Daily VMT Run the travel demand model for the plan horizon year. **Approach 4** - Caltrans Guidance Related to Calculating VMT for CEQA For Transit Projects that Reduce VMT: For projects that add transit service, an estimate of the net change in passenger-miles traveled that is predicted to result from the project multiplied by this number by 3 to get the total VMT reduction. Lane miles are found to generally have a statistically significant relationship with VMT of about 0.3–0.6 in the short run and between 0.7 and 1.0 in the long run. Elasticities are larger for models with more specific road types. A distributed lag model suggests a reasonable long-term lag structure. About 25% of VMT growth is estimated to be due to lane mile additions assuming historical rates of growth in road capacity. The results strongly support the hypothesis that added lane mileage can induce significant additional travel. General formula: NCST calculator can be used in the project area:		

				[% increase in lane miles] x [existing VMT] x [elasticity] = [VMT resulting from the project]		
Zero Emission Charging & Fueling Infrastructure	Automobiles and all street classifications	<u>Measures and metrics</u> • Electric vehicle miles traveled (EVMT) • Number of EV charging points or plugs • EV Dwell Time Near Public Charging Stations		<u>eVMT Methodology</u> Commonly used approaches to collecting eVMT data are through surveys, with some of the survey-based data sources mentioned below: • 2019 California vehicle survey data • Survey of more than 3,500 PEV owners conducted in California in May and June 2013. • Annual miles driven from the 2017 National Household Travel Survey (NHTS), which includes a self-reported and an imputed measure of annual VMT for a nationally representative sample of U.S. households. • Survey of PEV owners in California - The results show that PEV VMT is correlated with traditional factors like population density, built environment,	Jia and Chen (2022) ([19]) Tal et al. (2014) ([20]) Alberini et al. (2021) ([21]). Chakraborty et al. (2022) ([22]) Desai et al. (2022)[23]	**CAP 3 and 9**

[19] Jia, W., & Chen, T. D. (2022). Beyond Adoption: Examining Electric Vehicle Miles Traveled in Households with Zero-Emission Vehicles. Transportation Research Record, 2676(7), 642-654.
[20]Tal, G., Nicholas, M. A., Davies, J., & Woodjack, J. (2014). Charging behavior impacts on electric vehicle miles traveled: who is not plugging in?. Transportation Research Record, 2454(1), 53-60.
[21] Alberini, A., Burra, L. T., Cirillo, C., & Shen, C. (2021). Counting vehicle miles traveled: What can we learn from the NHTS?. Transportation research part D: transport and environment, 98, 102984.
[22] Chakraborty, D., Hardman, S., & Tal, G. (2022). Integrating plug-in electric vehicles (PEVs) into household fleets-factors influencing miles traveled by PEV owners in California. Travel Behaviour and Society, 26, 67-83.
[23] Desai, J., Mathew, J. K., & Li, H. (2022). Using Connected Vehicle Data for Assessing Electric Vehicle Charging Infrastructure Usage and Investment Opportunities. Institute of Transportation Engineers. ITE Journal, 92(3), 22-31.

				attitudes towards technology, and lifestyle preferences. Other available analysis is using data collected from California, Connecticut, Georgia, Indiana, Minnesota, North Carolina, Ohio, Pennsylvania, Texas, Utah and Wisconsin.		
		Costs		**Cost Description** • Charging station building, energy storage systems, charging station operation, battery investment, transformer investment, network expansion and greenhouse emissions. • Cost measures might also include time components such as charging and waiting time or travel time to access a station. • Profit maximization measures (in case private investors are building the charging infrastructure and the profit generated from the recharging service is interrelated with station location decisions). • Other objectives relate to service level, power or energy, environmental impact and deviations from shortest paths.	Kchaou-Boujelben, M. (2021)[24]	**CAP 3 and 9**
Safety		Crashes and fatalities	• Rate of traffic fatalities per 100 million vehicle	Five-year trend and whether the measure meets the desired trend	Washington DOT ([25])	**CAP 5**

[24] Kchaou-Boujelben, M. (2021). Charging station location problem: A comprehensive review on models and solution approaches. Transportation Research Part C: Emerging Technologies, 132, 103376.
[25] Washington DOT Statewide Transportation Policy Goals, accessed in May 22, 2023, https://wsdot.wa.gov/publications/fulltext/graynotebook/statewide-transportation-policy-goals-Sep17.pdf

	All modes and street classifications		miles traveled statewide • Rate of recordable incidents for every 100 full-time WSDOT workers			
		<u>Measures and Metrics used</u> • Reduction in Fatal and Serious Injury Crashes • Number of Traffic Fatalities • Number of Serious Traffic Injuries • Number of Fatalities Per 100 MVMT • Number of Serious Injuries Per 100 MVMT • Number of Non-Motorized Fatalities & Serious Injuries • Seat belt usage		Performance measures and metrics are based on the previous five years of crash data for Nevada DOT. Connecticut DOT uses a similar set of metrics in addition to calculating seat belt usage.	Nevada DOT ([26]) Connecticut DOT ([27])	**CAP 2 & 5**

[26] Nevada DOT, 2021 Performance Management Report, accessed on May 20, 2023, https://www.dot.nv.gov/home/showdocument?id=17402

[27] MAP-21 FHWA Performance Measures, Relating Connecticut Department of Transportation Performance Measures and National Transportation Performance Measures, 2022. https://portal.ct.gov/DOT/Performance-Measures/Performance-Measures

Climate Adaptation and Resiliency	All modes and street classifications	<u>Measures and Metrics</u> A number of commonly used measures/metrics that can be quantified include: • Evacuation route safety • Evacuation betweenness centrality (depicting connectivity) • Number of transportation options in evacuation corridors and routes • Total population exposed to extreme weather events • Access to transit dependent residents during extreme weather events, and • Quantified criticality, or importance, of the infrastructure or system.	Calculation Formula/Methodology: Flood Hazard Rate (FHR) for pedestrians can describe the safety of evacuation routes expressed as: FHR = MIN(1, U/Uc) where, U = flow velocity and Uc = incipient velocity, which is the minimum between $U_{toppling}$ and $U_{sliding}$. Another measure depicting connectivity of evacuation routes is the evacuation betweenness centrality, which is the ratio of the efficient evacuation paths that pass through node for a given origin and destination pair to the total number of evacuation paths between the same origin-destination pair. The population exposed can be calculated using a GIS analysis. Access can be calculated using the total vulnerable population to be moved to safer locations in disaster situations from extreme weather events.	Musolino et al. ([28]) Lujak and Giordani (2018) ([29]).	**CAP 1 & 6**

[28] Musolino, G., Ahmadian, R., & Xia, J. (2022). Enhancing pedestrian evacuation routes during flood events. Natural hazards, 112(3), 1941-1965.
[29] Lujak, M., & Giordani, S. (2018). Centrality measures for evacuation: Finding agile evacuation routes. Future Generation Computer Systems, 83, 401-412.

		<u>Measures</u> Clearance Time (Weather-Related Debris)	<u>Metrics</u> Average time to clear selected surface transportation facilities of weather-related debris after weather impact.	The guide is intended for practitioners involved in the day-to-day management, operations, and maintenance of surface transportation systems at State and local agencies.	Asam et al., 2015 aa	**CAP 6**
		Detours for Impacted Roadways	• Percentage of significant travel routes covered by weather-related diversion plans. • Percentage of agencies involved in transportation operations during weather events that have adopted multi-agency, weather-related transportation operations plans.			
		Disseminating Information	Time from beginning of weather event to posting of traveler information on variable message signs, public information broadcasts, etc.			
		Signal Timing Plans	Number of miles of arterials that have at least one special timing plan for inclement weather events			

Natural Resources and Ecosystems	All modes and street classifications	Land Consumption	Acreage of sensitive lands (e.g., parkland, habitat) on which new transportation infrastructure is built. Number of residential units and square feet of non-residential space near agricultural and natural resource lands. Number of lane miles of roadways, amount of square footage of buildings, and number of parking spaces in park-and-ride lots. Amount of new housing and jobs in greenfields. Acres of land consumed per residential unit. Acres of farmland converted to development.	Measures the amount of land consumed by new transportation infrastructure and/or new development served by new transportation infrastructure. The farmlands decision tree shown in the last page of this Appendix A indicates that if a project affects lands under Williamson Act Contract and requires federal approval or funding, then the Farmland Protection Policy Act requirements apply to the project ([30]).	EPA 2011[31]	**CAP 10**

[30] Chapter 23 – Farmlands, Caltrans, accessed on December 11, 2023, https://dot.ca.gov/programs/environmental-analysis/standard-environmental-reference-ser/volume-1-guidance-for-compliance/ch-23-farmlands

[31] EPA (2011). Guide to Sustainable Transportation Performance Measures. United States Environmental Protection Agency EPA 231-K-10-004.

Infill Development	All modes and street classifications	Measures and Metrics Mixed-ness index Various densities (Population, Job, Business, Intersection) Land Use Diversity Mixed-ness of Land Uses Length Bicycle + Pedestrian Network		Mixed-ness index indicates the easiness to access resources within short trips. Land use Diversity measured with the widely used "entropy" concept. High land use diversity is indicated by a high value of entropy, thus, higher levels of transit oriented development.	Several and a commonly cited reference is Huang et al. (2018)[32]	**CAP 2 & 8**
Freight Benefits - Throughput, Velocity, and Reliability	Highways	Average Daily Truck Traffic (ADTT) Truck Travel Time Reliability Freight movement (gross Tons) Truck Miles Reduced Travel Time Savings Reduced Truck GHG emissions	ADTT measured as truck volume of truck traffic per day on a road segment. Truck travel time index used for reliability calculation Freight movement is estimated using the volume or number of Rail Cars /TEU's/Bulk Cargo.	Truck Travel Time Reliability: Nevada DOT calculates the ratio of the longer travel times (95th percentile) to a "normal" travel time (50th percentile). Truck Travel Time Reliability (TTTR) Index is as per the National Performance Management Measure Rules 23 CFR Part 490.607. RAISE Discretionary Grant: Number of TEU/Railcar/Truck movements over project study area and truck miles reduced is calculated into reduced GHG emissions, carbon monoxide and particulate matter for mode of transportation defined in the project study area. Travel time savings for traffic measured over specified distance as defined by the project study area.	Nevada DOT ([33]) Federal Transportation Performance Measures (PM3) ([34])	**CAP 9**

[32] Huang, R., Grigolon, A., Madureira, M., & Brussel, M. (2018). Measuring transit-oriented development (TOD) network complementarity based on TOD node typology. Journal of transport and land use, 11(1), 305-324.
[33] Nevada DOT, 2021 Performance Management Report, accessed on May 20, 2023, https://www.dot.nv.gov/home/showdocument?id=17402
[34] FHWA Performance Measure 3 (PM3), accessed on May 22, 2023, https://www.govinfo.gov/content/pkg/FR-2017-01-18/pdf/2017-00681.pdf

				Variables include: queuing time or cross modal transport times.		
Congestion Relief	Highways	Mobility	Average incident clearance times Percentage of ferry trips departing on time On-time performance	Measured for the five-year trend and whether the measure meets the desired trend	Washington DOT ([35])	
		Urban congestion index	Total time that should be allowed to ensure on-time arrival for an average trip (for passenger vehicles and commercial trucks) within urban areas (areas with a population greater than 50,000 people).	The optimal value for all indices is 1.0, which means traffic is flowing at the posted speed limit. A score of 1.5 means 30 minutes should be planned for a 20-minute trip during free-flow travel (30 minutes divided by 20 minutes).	TxDOT ([36])	
		Mobility Index Score	Percentage of times highways clear of snow/ice during winter storms		Idaho DOT ([37])	
		Mobility Performance Measures	• Delay • Reliability • Mode Split • Snow Removal • Historic Mobility Index	Utah DOT Dashboard Metrics	Utah DOT ([38])	
		Job Accessibility by Car	Jobs accessible within 30-minute drive in Twin Cities during morning peak period	MinnesotaGO performance measure dashboard PR	Minnesota DOT ([39])	

[35] Washington DOT, accessed on May 21, 2023, https://www.wsdot.wa.gov/about/secretary/strategic-plan/dashboard/default.htm
[36] Optimize system performance, TxDOT, accessed on May 23, 2023. https://www.txdot.gov/data-maps/performance-dashboard/optimize-system-performance.html
[37] Idaho DOT, accessed on May 20, 2023, https://apps.itd.idaho.gov/Apps/Dashboard/
[38] Utah DOT, accessed on May 22, 2023, http://www.udot.utah.gov/strategic-direction/
[39] Minnesota DOT, https://performance.minnesotago.org/

		Travel time reliability	Percent of person-miles traveled on the network considered reliable			
		Freeway congestion	Percent of metro area freeway miles below 45 mph in am or pm peak			
		Measures and Metrics used Annual Hours of Peak Hour Excessive Delay Per Capita Percent of Person-Miles Traveled		23 CFR part 490.707(a): The NHS in urbanized areas with a population over 1 million for the first performance period and in urbanized areas with a population over 200,000 for the second and all other performance periods that are also in nonattainment or maintenance areas for ozone (O3), carbon monoxide (CO), or particulate matter (PM10 and PM2.5). For the percent of person-miles traveled, data sources used are from all traffic/vehicles data in National Performance Management Research Data Set (NPMRDS) or Equivalent - every 15-minutes.	Federal Transportation Performance Measures (PM3) ([40])	
Public Engagement	All modes	Participation level (%)		Percentage of individuals felt they were able to participate without an undue amount of trouble	Wagner (2013)[41]	
				Percentage of individuals who declined to attend, did so out of choice and not inability		

[40] FHWA Performance Measure 3 (PM3), accessed on May 22, 2023, https://www.govinfo.gov/content/pkg/FR-2017-01-18/pdf/2017-00681.pdf

[41] Wagner, J. (2013). Measuring performance of public engagement in transportation planning: three best principles. Transportation research record, 2397(1), 38-44.

			Percentage of individuals felt comfortable providing input in at least one of the platforms utilized		
			Percentage of individuals felt the platforms facilitated their attendance and participation		
			Percentage of individuals attending the events roughly represent the population		
			Percentage of individuals felt their opinions were heard and valued		
			Percentage of individuals felt the process encouraged collaboration		
			Percentage of individuals felt the activities were engaging		
			Percentage of individuals used the feedback mechanisms		
			Percentage of individuals felt their opinions would influence the decision- making		
			Percentage of individuals felt the engagement process, as a whole, was successful		
	All modes	Extent of public involvement	Respondent demographics, influence and impact of the public feedback on projects, early public involvement in timing, and accessibility by uthe se of multiple methods for participation.	NCHRP 905 (2019)[42]	
Benefits to Disadvantaged Communities	All modes	<u>Measures and Metrics</u> External Costs (noise, external crash damages, delays to active modes etc.)	Annual Costs Per User	Litman (2022)[43]	**CAP 4**
		Infrastructure Spending	Annual Spending Per Capita by various modes		**CAP 4**

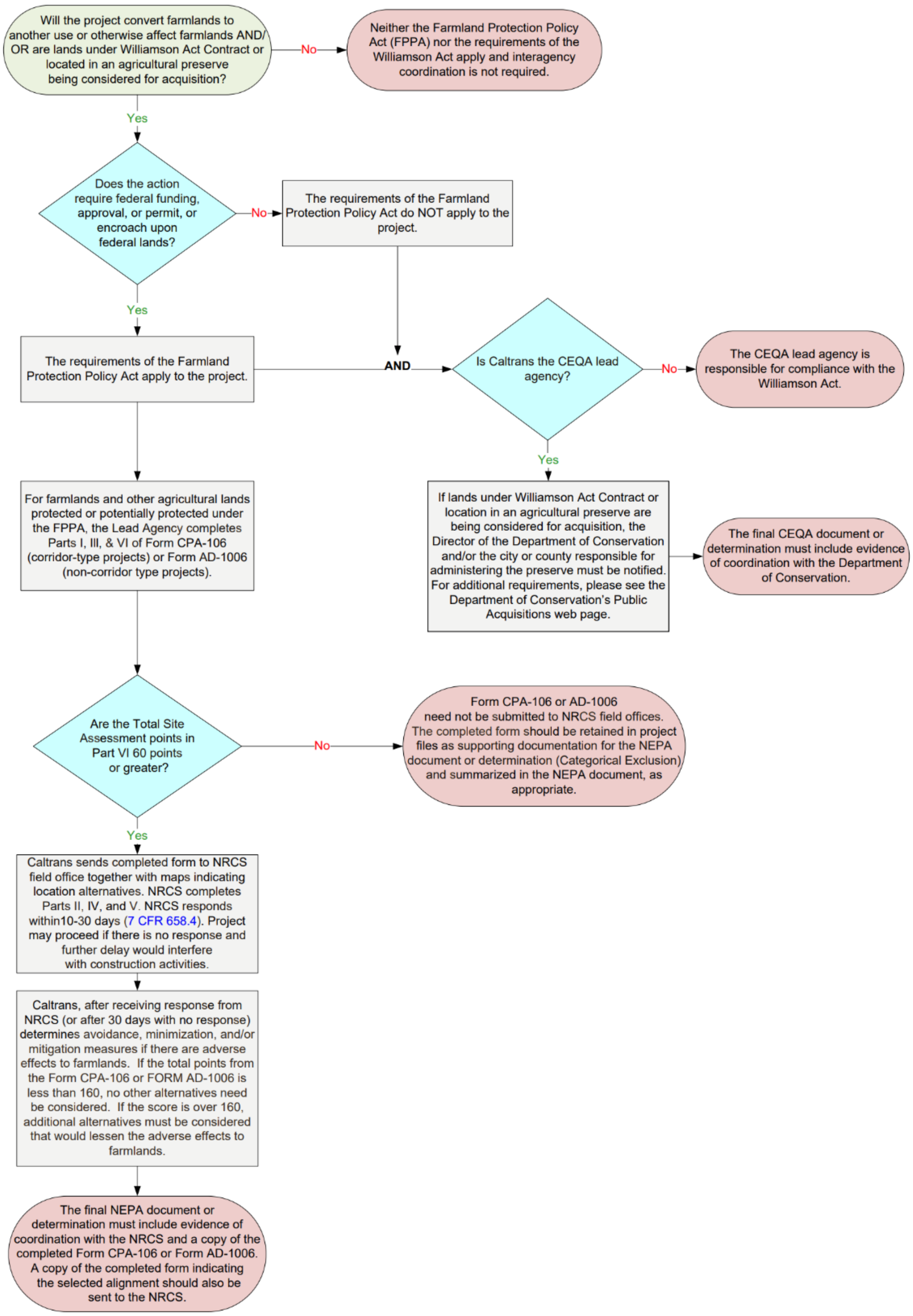
[42] NCHRP research report 905 (2019): 1-P2. National Academies of Sciences, Engineering, and Medicine. 2019. Measuring the Effectiveness of Public Involvement in Transportation Planning and Project Development. Washington, DC: The National Academies Press. https://doi.org/10.17226/25447.
[43] Litman, T. M. (2022). Evaluating Transportation Equity: Guidance for Incorporating Distributional Impacts in Transport Planning. Institute of Transportation Engineers. ITE Journal, 92(4), 43-49.

		Inclusivity		Comparing disparities between advantaged and disadvantaged groups, such as differences between non-drivers and drivers in the number of services and jobs that can be reached within 20 minutes. • Walk Score • Multimodal level-of-service ratings		**CAP 4**
		Affordability		• Location Affordability Index and the Housing and Transportation Affordability Index		**CAP 4**
		Measures Demographic Indicators	Metrics Low/High Income	Low-income: Median household income at or below 80% of the statewide median household income, High-income: Median household income was at or below the 2022 county low-income limit (established by the California Department of Housing and Community Development)	Caltrans Transportation EQI (2023)[44]	
			Percentage of race/ethnicity type	1 – (Total Not Hispanic or Latino Population of One Race White Alone/ Total Population)		
	Cars and trucks	Traffic Exposure Indicators	Traffic proximity and volume from the highway system and arterial roads in the state	Buffer is created around each road segment and the maximum car and truck Average Annual Daily Traffic (AADT) value for a given route is calculated		**CAP 4**
			Census block-level crash exposure based on crash history	Each crash weighted by the highest level of injury in the crash. Weighting factors were derived from the Cal-Benefit-Cost model		

[44] Caltrans Transportation Equity Index (EQI) Documentation, accessed on July 2, 2023. https://dot.ca.gov/-/media/dot-media/programs/planning-modal/documents/race-equity/eqibetadocumentation02212023a11y.pdf

	All modes	Access to Destinations Indicators	Decay-weighted cumulative reachable opportunities from a given origin	Number of opportunities that can be reached from a given origin using a given mode, or combination of modes		
			Multimodal Access to Destinations Ratio	Ratio is determined by dividing the weighted auto access to destinations score by the weighted multimodal access to destinations score		

Farmlands Decision Tree



Source: Chapter 23 – Farmlands, Caltrans ([45])

[45] Farmlands Decision Tree, Caltrans, accessed on December 11, 2023, https://dot.ca.gov/-/media/dot-media/programs/environmental-analysis/documents/ser/f0005640-farmlanddescisiontree-a11y.pdf

Appendix B

Criterion 1: Mode shift (active transportation, transit, and rail elements)

Measures/Metrics: Mode shift measures are defined for a specific mode and are dependent on the data availability for their calculation. Commonly used measures are ridership counts (transit), bike and pedestrian counts, travel cost impacts (complete streets), effectiveness of infrastructure interventions (all modes), etc. Most meaures/metrics align with the following CAPTI guiding principles:

CAP 1: Building towards an integrated, statewide rail and transit network
CAP 2: Investing in networks of safe and accessible bicycle and pedestrian infrastructure
CAP 7: Promoting projects that do not significantly increase passenger vehicle travel

Methodology/formula for Metric calculation: Mode shift metrics include differences in mode split 'before' and 'after' project implementation. For a more comprehensive estimation of the metric, short term or long term evaluation of mode shift can be reported – dependent on the data availability. A generally recommended formula for mode shift for active transportation modes, transit or rail, is expressed as a ratio or a percentage (say, P_x) as:

$$P_x = (P_{x,after} – P_{x,before})$$

where,

$P_{x,after}$ = ratio or percentage (or probability) of active transportation, transit, and rail mode users *after* project implementation

$P_{x,before}$ = ratio or percentage (or probability) of active transportation, transit, and rail mode users *before* project implementation

The ratio or percentage is often expressed as a probability term and is derived using the Multinomial logit (MNL) modeling, defined as:

$$P_{x,after} = (e^{Uact,after}/(e^{Uact,after} + e^{Uauto,after} + e^{Uother,after}))$$

where,

e = exponential constant, approximately equal to 2.718
$U_{act,after}$ = utility of active transportation mode, transit and rail *after* project implementation
$U_{auto,after}$ = utility of passenger cars *after* project implementation
$U_{other,after}$ = utility of other modes (besides active transportation, transit, rail, and passenger car) *after* project implementation

Similarly,

$P_{x,before} = (e^{Uact,before}/(e^{Uact,before} + e^{Uauto,before} + e^{Uother,before}))$

where,

e = exponential constant, approximately equal to 2.718
$U_{act,before}$ = utility of active transportation mode, transit and rail *before* project implementation
$U_{auto,before}$ = utility of passenger cars *before* project implementation
$U_{other,before}$ = utility of other modes (besides active transportation, transit, rail, and passenger car) *before* project implementation

Data sources/data collection: Preliminary information on mode shift potential can be obtained using stated-preference (SP) surveys. These surveys provide information on mode choice related to active transportation mode, transit, or rail modes.

Commonly used data sources, databases, or repositories that exist at the Federal, State and other local data sources is discussed below.

Federal:

- Transit ridership data: Transit ridership data can be used for estimating mode shift. The National Transit Database (NTD) of the FTA provides information and statistics on the transit systems of the United States. Data includes transit ridership information and trends from approximately 850 transit providers in urbanized areas ([46]). The NTD, however, publishes monthly total ridership data (and trends) for transit systems that are limited to those from urban areas. The data for California are listed under Region 9 of the NTD reports.

- Data.gov is the United States government's open data website that provides access to datasets published by agencies across the federal government on various modes, including crash data and counts ([47]). However, not all data needed for mode choice or mode shift calculations might be available on the website.

- OntheMap data ([48]): OnTheMap is a web-based mapping and reporting application that enables access to the LEHD Origin-Destination Employment Statistics (LODES) dataset, showing where people work and workers live. The data also include trip distances at the census block group level that can be used as input to build the utility function for mode choice models.

[46] The National Transit Database (NTD), Federal Transit Administration (FTA), accessed on May 22, 2023, https://www.transit.dot.gov/ntd
[47] Data.gov, accessed on July 22, 2023, https://catalog.data.gov/dataset
[48] OnTheMap, accessed on July 22, 2023. https://lehd.ces.census.gov/doc/help/onthemap/OnTheMapOnePager.pdf

State (of California):

- California Household Travel Survey (CHTS)([49]) – provides trip information that can be used to construct utility functions for various modes. The utility functions can thus be used as input to the mode split or choice formula of an MNL model. However, the drawback of using these data is that they are a decade old and can only provide an approximate modal split.

- California Statewide Travel Demand Model (CSTDM)([50]): The California Department of Transportation (Caltrans) operates the CSTDM. CSTDM can provide information on mode split and mode shift in collaboration with other state agencies, Metropolitan Planning Organizations (MPOs), Regional Transportation Planning Agencies (RTPAs), and other partners with an advanced multimodal tour/activity-based travel demand model.

Other local data sources:

Travel demand models (if available) include mode choice information for trips in the impacted site due to a project. Often, local transportation authorities possess models that can be utilized to assess potential mode shift due to the project.

Transportation planning software is commonly used for travel demand modeling (TDM). It requires primary inputs such as information on the transportation network, trip tables with origin-destination information, utility functions for mode split and the impacted region divided into zones with centroids treated as origin and destinations. TDM outputs are trips due to mode shift resulting from the project or a change in an element of the transportation network ([51]). The data collected through TDM outputs from a mode shift can become complex depending on the network size, trip tables, and the number of zones the TDM software handles.

Other techniques for mode shift estimation due to a project are based on prediction models that estimate demand for a mode and can be used to determine mode shift. Data mining techniques, involving statistical regression are used for demand prediction ([52]).

Applicable software package/tool: Several TDM software packages can be used for mode shift estimation and these include TransCAD, PTV Visum, Cube etc. Statistical regression modeling for prediction can also be deployed for mode shift estimation. Regression modeling can be carried out using SPSS, SAS, R, and Python.

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[49] 2010-2012, California Household Travel Survey (CHTS)"Transportation Secure Data Center." (2017). National Renewable Energy Laboratory. Accessed Jan. 15, 2017: www.nrel.gov/tsdc.

[50] California Statewide Travel Demand Model (CSTDM), accessed on July 22, 2023, https://dot.ca.gov/programs/transportation-planning/division-of-transportation-planning/data-analytics-services/statewide-modeling

[51] Travel Demand Modeling, Metropolitan Washington Council of Governments, accessed on May 23, 2023, https://www.mwcog.org/transportation/data-and-tools/modeling/inputs-outputs/

[52] Ashqar, H. I., Elhenawy, M., & Rakha, H. A. (2019). Modeling bike counts in a bike-sharing system considering the effect of weather conditions. Case studies on transport policy, 7(2), 261-268.

Complexities in data collection and calculations: Complexity in computing the actual mode shift is very high due to the TDM involved.

Criterion 2: Vehicle Miles Travelled (VMT)

Measures/Metrics: VMT is usually calculated by adding up all the miles driven by all the cars and trucks on all the roadways in a region (TTI, 2016[53]), and is represented as a change in daily VMT for 'no build' and 'build' scenarios of a project. The metric aligns with the following CAPTI guiding principle:

CAP 7: Promoting projects that do not significantly increase passenger vehicle travel

Methodology/formula for Metric calculation: A common approach to VMT data collection involves traffic count from a subset of roadways and interpolated to determine the overall VMT. Further, temporal or seasonal adjustment factors are accounted for road segments that are not as extensively sampled ([54]).

VMT = Vehicle Volume multiplied by Impacted Length of the Project in a "Build" Scenario **minus** Vehicle Volume multiplied by impacted Length of the Project in a "No Build" Scenario. ([55])

Data sources/data collection: The three levels of data sources for VMT are:

Federal:

Resources for VMT calculation include the following:

Highway Statistics Series, Policy and Governmental Affairs, Office of Highway Policy Information, FHWA ([56]): With the vast majority of highway data submitted by the States (and by California), the series publication provides annual selected statistical tabulations relating to highway transportation, including vehicle miles traveled. Data are categorized into vehicle miles traveled by rural and urban highway systems and further classified into interstate, other freeways and expressways, other principal arterials, minor arterial, major collector, minor collector and local and total.

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[53] Williams, T. A., Chigoy, B., Borowiec, J., & Glover, B. (2016). Methodologies Used to Estimate and Forecast Vehicle Miles Travelled (VMT): Final Report. Policy Research Center, Texas A & M Transportation Institute.

[54] Fan, J., Fu, C., Stewart, K., & Zhang, L. (2019). Using big GPS trajectory data analytics for vehicle miles traveled estimation. Transportation research part C: emerging technologies, 103, 298-307.

[55] Ashqar, H. I., Elhenawy, M., & Rakha, H. A. (2019). Modeling bike counts in a bike-sharing system considering the effect of weather conditions. Case studies on transport policy, 7(2), 261-268.

[56] https://www.fhwa.dot.gov/policyinformation/statistics/2021/vm2.cfm

2023 FHWA Forecasts of VMT ([57]): The forecasts of National VMT are based on long-term economic and demographic outlooks. These forecasts are produced using statistical models using a variety of factors, including historical variation and growth in motor vehicle use.

Freight Analysis Framework (FAF[58]): FAF4 network database provides information on both the daily and the forecasted traffic vehicle miles of travel in a GIS platform. The data attributes contain information on both passenger cars and trucks.

State (of California):
Monthly Vehicle Miles of Travel (MVMT) report, often called the "Trend" report, is produced by the Traffic Data Branch, Caltrans ([59]).

California Induced Travel Calculator, NCST ([60]):
This calculator allows users to estimate the VMT induced annually as a result of expanding the capacity of publicly owned roadways, like those managed by the Caltrans, in one of California's urbanized counties (counties within a metropolitan statistical area (MSA)). The calculator applies only to interstate highways (class 1), other freeways and expressways (class 2), and other principal arterials (class 3).

Existing guidance for evaluating VMT impacts of projects in rural counties recommend the use of travel demand model (TDM) ([61]).

Other local data sources:
Examples include City of Los Angeles VMT Calculator ([62]) which uses trip length information from the TDF Model to calculate vehicle miles traveled.

Complexities in data collection and calculations: Accuracy and reliability of VMT data is often questionable, especially for roads in the rural areas.

Criterion 3: Zero Emission Charging & Fueling Infrastructure

Measures/Metrics: Measures and metrics include electric vehicle miles traveled, number of EV charging points or plugs and EV dwell times near charging stations. The metrics align with the following CAPTI guiding principles:

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[57]https://www.fhwa.dot.gov/policyinformation/tables/vmt/vmt_forecast_sum.cfm#:~:text=Combination%20truck%20VMT%20is%20projected,entire%2030%2Dyear%20forecast%20period.

[58] Freight Analysis Framework, Federal Highway Administration (FHWA), accessed on August 19, 2023, https://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf4/netwkdbflow/index.htm

[59] Monthly Vehicle Miles of Travel – Caltrans, accessed on August 25, 2023, https://dot.ca.gov/programs/traffic-operations/census/mvmt

[60] https://travelcalculator.ncst.ucdavis.edu/

[61] Caltrans' Transportation Analysis Under CEQA (TAC) First Edition: Evaluating Transportation Impacts of State Highway System Projects, September 2020, accessed on December 6, 2023, https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/sb-743/2020-09-10-1st-edition-tac-fnl-a11y.pdf

[62] City of Los Angeles VMT Calculator, accessed on December 6, 2023, https://ladot.lacity.org/sites/default/files/documents/vmt_calculator_documentation-2020.05.18.pdf

CAP 3: Including investments in light, medium, and heavy-duty zero-emission-vehicle infrastructure
CAP 9: Developing a zero-emission freight transportation system

Methodology/formula for Metric calculation: Projects that require locating zero-emission charging and fueling infrastructure deploy an optimization model with constraints, and define parameters and objectives. The main objective in using such models is to minimize the system's annual charging and infrastructure costs ([63]).

Data sources/data collection: Data sources for California include the following:

Electric vehicle miles traveled (EVMT): Data on EVMT can be obtained from the California Energy Commission ([64]). These data are based on 2019 California Vehicle Survey.

Other commonly used approaches to collecting EVMT data are through surveys, with some of the survey-based data sources mentioned below:

- 2019 California vehicle survey data ([65])
- Survey of more than 3,500 PEV owners conducted in California in May and June 2013. ([66])
- Annual miles driven from the 2017 National Household Travel Survey (NHTS), which includes a self-reported and an imputed measure of annual VMT for a nationally representative sample of U.S. households. ([67])
- Survey of PEV owners in California - The results show that PEV VMT is correlated with traditional factors like population density, built environment, attitudes towards technology, and lifestyle preferences. ([68])

Number of EV charging points or plugs: Two important and useful data sources were identified in this research for determining number of EV charging points or plugs as follows:

[63] Li, X., & Jenn, A. (2022). An integrated optimization platform for spatial-temporal modeling of electric vehicle charging infrastructure. Transportation Research Part D: Transport and Environment, 104, 103177.
[64] Vehicle Miles Traveled by Fuel Type, California Energy Commission, accessed on August 25, 2023, https://www.energy.ca.gov/data-reports/surveys/california-vehicle-survey/vehicle-miles-traveled-fuel-type
[65] Jia, W., & Chen, T. D. (2022). Beyond Adoption: Examining Electric Vehicle Miles Traveled in Households with Zero-Emission Vehicles. Transportation Research Record, 2676(7), 642-654.
[66]Tal, G., Nicholas, M. A., Davies, J., & Woodjack, J. (2014). Charging behavior impacts on electric vehicle miles traveled: who is not plugging in?. Transportation Research Record, 2454(1), 53-60.
[67] Alberini, A., Burra, L. T., Cirillo, C., & Shen, C. (2021). Counting vehicle miles traveled: What can we learn from the NHTS?. Transportation research part D: transport and environment, 98, 102984.
[68] Chakraborty, D., Hardman, S., & Tal, G. (2022). Integrating plug-in electric vehicles (PEVs) into household fleets-factors influencing miles traveled by PEV owners in California. Travel Behaviour and Society, 26, 67-83.

i) The National Renewable Energy Laboratory (NREL)[69]: The NREL houses a query-based database on alternative fuel stations that includes electric charging stations – with station id, last updated data, nearest stations, stations nearby route, etc., and
ii) California Energy Commission ([70]). Data on charger counts combine CEC voluntary survey results with public and shared private chargers listed by the Alternative Fuels Data Center (AFDC) and PlugShare. The counts are updated quarterly.

EV dwell time near public charging stations: Dwell times for EV depend on the charger types and speeds. An estimate for the dwell times can be obtained from the information on charger types and speeds by the USDOT ([71]). As an example, the charging station may have Level 1, Level 2 or Direct Current Fast Charging (DCFC) equipment. The DCFC offers rapid charging along heavy-traffic corridors at installed stations.

Other sources of EV dwell times data comprise units consumed with the time taken for full charge at charging stations - but the data collection has to be in compliance with privacy laws and regulations for the use of the stations (whether public or private). Alternate means of estimating EV dwell times can be through tracking trajectories of EV vehicles at specific locations (such as parking lot, restaurants etc.) and time spent on such locations through analysis ([72]). Private data sources that need to be purchased include those from the StreetLight Data ([73]).

Applicable software package/tool: Variety of applicable EV Planning Resources are available by the USDOT and include tools for EV infrastructure planning and implementation ([74]). For example, Shift2Electric is a noted workplace charging planning tool to help plan and implement charging stations.

Complexities in data collection and calculations: Complexities in data collection and calculations can arise due to optimization techniques deployed for the project evaluation.

[69] National Renewable Energy Laboratory, "All Stations API." https://developer.nrel.gov/docs/transportation/alt-fuel-stations-v1/all/(Accessed July 28, 2021).
[70] Electric Vehicle Chargers in California, California Energy Commission (CEC), accessed on August 14, 2023, https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/electric-vehicle
[71] Charger Types and Speeds, United States Department of Transportation (USDOT), accessed on August 10, 2023. https://www.transportation.gov/rural/ev/toolkit/ev-basics/charging-speeds
[72] Desai, J., Mathew, J. K., & Li, H. (2022). Using Connected Vehicle Data for Assessing Electric Vehicle Charging Infrastructure Usage and Investment Opportunities. Institute of Transportation Engineers. ITE Journal, (3), 22-31.
[73]StreetLight Data, Big Data for Mobility, accessed on September 6, 2023, https://www.streetlightdata.com/refine-ev-charging-infrastructure-plan/#dashboard
[74] EV Planning Resources: Implementation, Installation, and Maintenance, USDOT, accessed on August 25, 2023, https://www.transportation.gov/rural/ev/toolkit/planning-resources/implementation-installation-and-maintenance

Criterion 4: Safety

Measures/Metrics: Reductions in fatalities, including non-motorized fatalities, and crashes is a commonly used measure and metric of project evaluation for safety. The metrics align with the following CAPTI guiding principles:

CAP 2: Investing in networks of safe and accessible bicycle and pedestrian infrastructure
CAP 5: Making safety improvements to reduce fatalities and severe injuries of all users towards zero

Methodology/formula for Metric calculation: Reductions in fatalities or crashes, as a count, can be determined if a project is anticipated to bring out such benefits in safety.

Data sources/data collection: Various data sources exist as a data repository for historical crashes. These are explained below:

Federal:
Fatality Analysis Reporting System (FARS): Through the use of Fatality and Injury Reporting System Tool (FIRST), a user can construct customized queries from the FARS and from the Crash Report Sampling System (CRSS) ([75]). However, the FARS data are aggregates of the crashes or fatalities at the spatial scale of cities. Other sources of data also include Early Notification (EN) data and Monthly Fatality Counts (MFC) that are used for the early estimate of motor vehicle traffic fatalities as projections ([76]).

State (of California)/local:
The Statewide Integrated Traffic Records System (SWITRS) is a commonly used database to collect and process data gathered from a collision scene in California ([77]). The Transportation Injury Mapping System (TIMS), developed by UC Berkeley SafeTREC's GIS Program, provides quick, easy and free access to California crash data in a geo-coded format ([78]). As of 2023, crash data from 2011 to 2022 are available through TIMS.

Complexities in data collection and calculations: With geo-coded crash locations, determining safety improvements from a project that can potentially reduce or eliminate crashes at a site can be quickly estimated.

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[75] National Highway Traffic Safety Administration (NHTSA), USDOT, accessed on August 24, 2023, https://cdan.dot.gov/query
[76] Traffic Safety Facts, NHTSA, accessed on August 24, 2023, https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813482
[77] Statewide Integrated Traffic Records System (SWITRS), California Highway Patrol, accessed on August 24, 2023, https://iswitrs.chp.ca.gov/Reports/jsp/index.jsp
[78] Transportation Injury Mapping System (TIMS), accessed on August 24, 2023, https://tims.berkeley.edu/

Criterion 5: Climate Adaptation and Resiliency

Measures/Metrics: A number of commonly used measures/metrics that can be quantified include ([79],[80]):

i) Evacuation route safety
ii) Evacuation betweenness centrality (depicting connectivity)
iii) Number of transportation options in evacuation corridors and routes
iv) Total population exposed to extreme weather events
v) Access to transit dependent residents during extreme weather events, and
vi) Quantified criticality, or importance, of the infrastructure or system.

The metrics generally align with the following CAPTI guiding principles:

CAP 1: Building towards an integrated, statewide rail and transit network
CAP 6: Assessing physical climate risk

Methodology/formula for Metric calculation: Flood Hazard Rate (FHR) for pedestrians can describe the safety of evacuation routes expressed as ([81]):

FHR = MIN(1, U/Uc)

where U = flow velocity and Uc = incipient velocity, which is the minimum between $U_{toppling}$ and $U_{sliding}$.

Another measure depicting connectivity of evacuation routes is the evacuation betweenness centrality, which is the ratio of the efficient evacuation paths that pass through node for a given origin and destination pair to the total number of evacuation paths between the same origin-destination pair ([82]).

The population exposed can be calculated using a GIS analysis.

Access can be calculated using the total vulnerable population to be moved to safer locations in disaster situations from extreme weather events.

Data sources/data collection/tool: Transportation network data can be obtained from various sources including Caltrans GIS, Freight Analysis Framework (FAF), etc.

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[79]https://documents.coastal.ca.gov/assets/climate/slr/vulnerability/residential/RevisedDraftResidentialAdaptationGuidance.pdf
[80] Local Hazard Mitigation Plan, County of Orange & Orange County Fire Authority, accessed on August 22, 2023, https://ocsheriff.gov/sites/ocsd/files/2022-03/2021%20County%20of%20Orange%20and%20Orange%20County%20Fire%20Authority%20Local%20Hazard%20Mitigation%20Plan.pdf
[81] Musolino, G., Ahmadian, R., & Xia, J. (2022). Enhancing pedestrian evacuation routes during flood events. Natural hazards, 112(3), 1941-1965.
[82] Lujak, M., & Giordani, S. (2018). Centrality measures for evacuation: Finding agile evacuation routes. Future Generation Computer Systems, 83, 401-412.

Population data can be obtained from the US Census Bureau, as well as the Longitudinal Employer-Household Dynamics (LEHD) data ([83]) – which provides information on concentration of low-income population.

Complexities in data collection and calculations: Quantitative metrics can be calculated easily depending on the data availability. However, the centrality calculation for connectivity can be a bit complex due to the network-based distance calculations between origins and destinations.

Criterion 6: Natural Resources and Ecosystems

Measures/Metrics: The primary measure/metric is the land consumption that accounts for the acreage of sensitive land that the project consumes or affects. The guidance is mainly provided by the EPA for this measure ([84]). The metric aligns with the following CAPTI guiding principle:

CAP 10: Protecting natural and working land

Methodology/formula for Metric calculation: GIS can be used to carry out a buffer analysis for determining project impacts. With the buffer (as distance) around a project, the acreage of the land consumption can be calculated. The formula for determining the impacts from a project can then be calculated as the post acreage or extent of the affected land, water or air minus the acreage pre project implementation. EPA 2011 provides guidance on the methodology by use of the acreage of sensitive lands (e.g., parkland, habitat) on which new transportation infrastructure is built, amount of new housing and jobs in greenfields, acres of land consumed per residential unit, etc.

The farmlands decision tree shown in Appendix indicates that if a project affects lands under Williamson Act Contract and requires federal approval or funding, then the Farmland Protection Policy Act requirements apply to the project ([85]).

Data sources/data collection: GIS can be a very effective tool in determining the extent of the project impacts, while data on an existing natural resource or ecosystem, wildlife etc. can be obtained from various data sources such as the National Wildlife Refuge System GIS Data and Mapping Tools of the US Fish & Wildlife Service ([86]) and California Department of Fish & Wildlife ([87]).

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[83] Longitudinal Employer-Household Dynamics (LEHD) data, OnTheMap, accessed on August 22, 2023, https://onthemap.ces.census.gov/

[84] EPA (2011). Guide to Sustainable Transportation Performance Measures. United States Environmental Protection Agency EPA 231-K-10-004.

[85] Chapter 23 – Farmlands, Caltrans, accessed on December 11, 2023, https://dot.ca.gov/programs/environmental-analysis/standard-environmental-reference-ser/volume-1-guidance-for-compliance/ch-23-farmlands

[86] U.S. Fish & Wildlife Service, accessed on August 25, 2023, https://www.fws.gov/service/national-wildlife-refuge-system-gis-data-and-mapping-tools

[87] Geographic Information Systems (GIS) Services,

Applicable software package/tool: ArcGIS is the most used software for performing GIS analysis in estimating project-level impacts and performance measures.

Complexities in data collection and calculations: The complexity in analysis is dependent on the quality of data availability on the natural resources and ecosystems for assessing the extent of a project's spatial impact.

Criterion 7: Infill Development

Measures/Metrics: Both measures and metrics are used interchangeably for determining a quantified value of infill development, and these include, indices of mixed use, densities, land use diversity etc. Some of the metrics align with the following CAPTI guiding principles:

CAP 2: Investing in networks of safe and accessible bicycle and pedestrian infrastructure
CAP 8: Promoting compact infill development while protecting residents and businesses from displacement

Methodology/formula for Metric calculation: Various predicting models are used for determining infill development – some of these models utilize machine learning (ML) algorithms to model residential infill development ([88]) and other theoretical approaches such as the cellular automata in urban densification ([89]). Land use models are also used for predicting future land use change modeling research ([90]).

Applicable software package/tool: CUBE is a commonly used software for modeling and analyzing the effects of new projects on a city's transportation network, land-use, and its population ([91]).

Complexities in data collection and calculations: Complexities can arise with the availability of land-use data, modeling and simulation of infill development.

Criterion 8: Freight Benefit - Throughput, Velocity, and Reliability

Measures/Metrics: Measures/metrics include annual average daily truck traffic (AADTT) for throughput, average speed or the 85th percentile speed, truck travel time reliability, reduced truck GHG emissions etc. Some of the metrics align with the following CAPTI guiding principle:

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[88] Kim, D., Shim, J., Park, J., Cho, J., & Kumar, S. (2022). Supervised machine learning approaches to modeling residential infill development in the city of Los Angeles. Journal of Urban Planning and Development, 148(1), 04021060.
[89] Chakraborty, A., Sikder, S., Omrani, H., & Teller, J. (2022). Cellular automata in modeling and predicting urban densification: Revisiting the literature since 1971. Land, 11(7), 1113.
[90] Verburg, P. H., Schot, P. P., Dijst, M. J., & Veldkamp, A. (2004). Land use change modelling: current practice and research priorities. GeoJournal, 61, 309-324.
[91] https://www.bentley.com/software/cube/

CAP 9: Developing a zero-emission freight transportation system

Methodology/formula for Metric calculation: determining AADTT from a project requires measuring (forecast) truck volume. For simple AADTT calculations, two methods are suggested– simple average method and AASHTO method ([92]). However, forecast truck volume resulting from a project can only be calculated using a suitable travel demand model in the region that captures truck movement.

In California, the California Statewide Freight Forecasting and Travel Demand Model (CSF2TDM), developed by Caltrans, forecasts short and long-distance travel by all commercial vehicle that travel throughout the state ([93]). Other regional or local travel demand models can also be used for predicting truck traffic (as throughput on a roadway), average speed, and truck travel time reliability.

In case a suitable TDM of a region is not available, the practice is to borrow the TDM parameters from a sister region with a similar demographics and travel patterns.

Data sources/data collection: Data collection is usually carried out with the output from the TDM deployed and hence, all data collected are forecasts of the metrics. However, the accuracy of the metric outputs from the TDM will depend on how accurately the TDM is built based on the four-steps of the modeling – namely, trip generation, trip distribution, mode choice and trip assignment.

Federal:
The usual Freight Analysis Framework (FAF) includes information on truck volumes, tonnage and average speed for all freight truck roadways of the nation. The FAF5 provides estimates for tonnage and value by regions of origin and destination, mode for base year 2017 and 30- year forecasts. The forecasts are for the future freight demands at five-year increments, representing three different economic growth scenarios through 2050. However, for evaluating a project for the impact it has on freight benefits, the FAF forecasts will be inaccurate and hence, a TDM analysis needs to be carried out.

State (of California)/other local data sources:
Caltrans GIS contains information on truck traffic data on various roads and freeways. As with FAF data, a TDM can determine if a project will result in increased freight benefits in terms of throughout, average speed, travel time reliability etc.

Complexities in data collection and calculations: Complexities in TDM can make the process of assessing project evaluation for determining freight benefit a complex process.

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[92]Traffic Data Computation Method, POCKET GUIDE, FHWA, Publication No. FHWA-PL-18-027, USDOT, accessed on August 22, 2023, https://www.fhwa.dot.gov/policyinformation/pubs/pl18027_traffic_data_pocket_guide.pdf

[93] Statewide Modeling, California Statewide Freight Forecasting and Travel Demand Modeling (CSF2TDM), accessed on August 22, 2023, https://dot.ca.gov/programs/transportation-planning/division-of-transportation-planning/data-analytics-services/statewide-modeling/california-statewide-modeling-freight-forecasting-travel-demand-model

Criterion 9: Congestion Relief

Measures/Metrics: Various state DOTs use a variety of measures and metrics for congestion relief. Measures include mobility, congestion index, reliability, accessibility, delay, etc. Metrics are typically the clearance time, on-time arrival for a trip, percentage of person-miles traveled, etc.

Methodology/formula for Metric calculation: Each separate measure is calculated for a project using a travel demand model (TDM) that requires at least the transportation network information and trip details (origin-destination pairs, volumes etc.).

The calculations for measures such as delay, reliability and congestion index are determined through outputs from the TDM.

Data sources/data collection: Data needed for the TDM can be for modes primarily including cars, transit and freight trucks for determining congestion relief. Projects that impact other modes can include freight rail and ships (at the seaports).

Various data sources available at the Federal, State, and local level are noted below:

Federal:
Annual average daily traffic (AADT) and Annual average daily truck traffic (AADTT) are the most readily available data from the FHWA through the Freight Analysis Framework (FAF). The FAF is produced through a partnership between Bureau of Transportation Statistics (BTS) and the FHWA ([94]). It integrates data from a variety of sources using the 2017 Commodity Flow Survey and is primarily for freight movement among states and major metropolitan areas.

State (of California):
Caltrans GIS Data webpage provides information on bottlenecks across line segments of heavy congestion during peak AM and/or PM periods along the California State Highway System ([95]).

Applicable software package/tool: Various TDM software packages for planning and simulation can be used to understand congestion relief from projects. These TDM software packages include TransCAD, PTV Visum etc.

Complexities in data collection and calculations: Accuracy and reliability of VMT data is often questionable, especially for roads in the rural areas.

Criterion 10: Public Engagement

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[94] Freight Analysis Framework, Federal Highway Administration (FHWA), accessed on August 19, 2023, https://ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm

[95] Caltrans GIS Data, accessed on August 25, 2023, https://gisdata-caltrans.opendata.arcgis.com/datasets/9509bf8a475f49b4a9c79bac15f8b479_0/about

Measures/Metrics: Public participation level expressed in percentage that constitutes measures with goals as noted by Wagner (2013)[96] and presented in table below:

TABLE 2 Example Performance Scorecard

Principle	Objective	Measure	Goal	Results
Accessible	All who wished to participate had the ability to do so without an undue burden	Individuals felt they were able to participate without an undue amount of trouble	80% or more affirmative responses	70%
		Individuals who declined to attend did so out of choice and not inability	80% or more affirmative responses	90%
		Individuals felt comfortable providing input in at least one of the platforms utilized	80% or more affirmative responses	80%
		Individuals felt the platforms facilitated their attendance and participation	80% or more affirmative responses	80%
	Events were democratic and representative of the population	Individuals attending the events roughly represent the population	Minority groups' attendance rates were within 5 percentage points of their actual share in the population	Yes
Engaging	The process fostered an environment favorable for input and collaboration	Individuals felt their opinions were heard and valued	80% or more affirmative responses	70%
		Individuals felt the process encouraged collaboration	80% or more affirmative responses	90%
		Individuals felt the activities were engaging	80% or more affirmative responses	70%
	The process was ongoing	Individuals used the feedback mechanisms	50% or more of the individuals used the feedback mechanisms	60%
Outcome-oriented	The input provided from the public influenced the decision-making process	Individuals felt their opinions would influence the decision making	70% or more affirmative responses	70%
	The process successfully engaged the public	Individuals felt the engagement process, as a whole, was successful	70% or more affirmative responses	75%

Data sources/data collection: Surveys are considered as the most effective method of measuring public participation. Guidance is provided by NCHRP 905 – "*Measuring the Effectiveness of Public Involvement in Transportation Planning and Project Development (2019)*" ([97]). Data collection that pertains to the extent of public participation in a project using surveys may use questions that require rating on a five-point scale (varying from 'strongly disagree' to 'strongly agree'), with "don't know" and "not applicable" options. Data collection through survey on projects should involve the following:

- Respondent demographics
- Influence and impact of public feedback on project decisions
- Transparency and clarity
- Timing of public involvement
- Inclusion of representative of all targeted and affected population
- Targeted engagement
- Accessibility by means of multiple methods for public participation
- Open-ended question, and
- Public involvement experience

[96] Wagner, J. (2013). Measuring performance of public engagement in transportation planning: three best principles. Transportation research record, 2397(1), 38-44.

[97] NCHRP research report 905 (2019): 1-P2. National Academies of Sciences, Engineering, and Medicine. 2019. Measuring the Effectiveness of Public Involvement in Transportation Planning and Project Development. Washington, DC: The National Academies Press. https://doi.org/10.17226/25447.

Complexities in data collection and calculations: The accuracy and reliability of VMT data are often questionable, especially for roads in rural areas.

Criterion 11: Benefits to Disadvantaged Communities

Measures/Metrics: Benefits to disadvantaged communities can be measured in a variety of ways. Some commonly used measures include access to destination indicators, traffic exposure indicators, demographic indicators, affordability, and inclusivity. Some of the metrics align with the following CAPTI guiding principle:

CAP 4: Strengthening our commitment to social and racial equity by reducing public health harms and maximizing benefits to disproportionately impacted disadvantaged communities

Metrics: The measures vary from one to the other so there are different metrics that are considered depending on the measure.

- *Access to Destination Indicators*: Can be found by using the decay-weighted cumulative reachable opportunities from a given origin or a multimodal access to destination ratio using access scores.
- *Traffic Exposure Indicators*: Include traffic proximity and volume from the highway system and arterial roads in the state or a census block-level crash exposure based on crash history.
- *Demographic Indicators*: This is typically focused on household income or race/ethnicity percentage measure.
- *Affordability*: Analyzing the cost burden and affordability
- *Inclusivity*: Disparities between advantaged and disadvantaged groups

Methodology/formula for Metric calculation: Various methodologies and formulas can be used depending on the metric that is considered.

$$\text{Multimodal Access to Destination Ratio} = \frac{Weighted\ auto\ access\ to\ destination\ score}{weighted\ multimodal\ access\ to\ destination\ score}$$

Or the decay-weighted cumulative reachable opportunities from a given origin can be calculated with ArcGIS/Python. Both results can then be displayed on GIS software to indicate the areas with the highest ratio.

Traffic Exposure can is typically displayed through buffers around each road segment using the maximum car and truck Average Annual Daily Traffic (AADT) value for given routes. Crash exposure is similarly shown but weighted by the highest level of injury in the crash.

Demographic Indicators can be shown with,

$$\text{Non-White Percentage} = 1 - \left(\frac{\text{Total Not Hispanic or Latino Population of One Race White Alone}}{\text{Total Population}}\right)$$

Determined for the affected block has a high non-white percentage it should be screened for inclusion.
Low Income households are typically found through OnTheMap and other similar websites to find those households with a median income at or below the 80% of statewide median household income.

Affordability is typically displayed through location affordability or Housing and Transportation Affordability Index to calculate the savings provided by more affordable modes and accessibility to locations.

Inclusivity can be shown through walk scores and multimodal level of service ratings. It can also be shown by comparing disparities between advantaged and disadvantaged groups such as difference in the number of jobs and services that can be reached within 20 minutes for non-drivers and drivers.

Data sources/data collection: Data sources will vary depending on the given measure.

- OntheMap ([98]): OnTheMap is a web-based mapping and reporting application that enables access to the LEHD Origin-Destination Employment Statistics (LODES) dataset, showing where people work and workers live. The data also include trip distances at the census block group level that can be used as input to build the utility function for mode choice models.

- Data.gov is the United States government's open data website that provides access to datasets published by agencies across the federal government on various modes, including crash data and counts ([99]). This data is typically used for traffic exposure.

- The National Transit Database (NTD) of the FTA provides information and statistics on the transit systems of the United States. Data includes transit ridership information and trends from approximately 850 transit providers in urbanized areas ([100]). The NTD can help assess public transportation needs and benefits to disadvantaged communities. The data for California are listed under Region 9 of the NTD reports.

- The Environmental Protection Agency (EPA) has tools to help identify communities facing environmental justice challenges such as EJScreen ([101]). This can help pinpoint areas where transportation projects may have impacts on disadvantaged communities.

Applicable software package/tool: GIS software such as ArcGIS and QGIS can be used to map demographic data, environmental factors, or other criteria.

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[100] The National Transit Database (NTD), Federal Transit Administration (FTA), accessed on May 22, 2023, https://www.transit.dot.gov/ntd

Complexities in data collection and calculations: Some complexities include defining a disadvantaged community as the criteria may change from one region to another and are often multifaceted.

Appendix C

Metric Score Formulation

Criterion 1: Mode shift (active transportation, transit, and rail elements)

Travel demand models (TDMs) are usually deployed to estimate mode shift. In the absence of a TDM, alternate methods are noted in literature, which are approximations to TDM mode shift. One such method is proposed by Bahbouh et al. (2017)[102] and applied by Wasserman et al. (2022)[103] that is modified and adapted for estimating mode shift and is thus we purpose for use in this research. Further details of this mdoe shift estimation (as a percentage) resulting from a project is explained below.

Potential mode shift (in percentage), *m = (% alignment with **Proximity**)* × *(% alignment with **Parallelism**)* × *(% alignment with **Trip Distance**)*

where,

Proximity indicates the number of people traveling within close proximity of the project. The proximity can be set in terms of distance of the project from home or work locations.

Parallelism indicates trips going in the same direction as the project's orientation.

Trip Distance indicates how far people travel using transit and active modes of transportation with the project infrastructure.

The metric score, *S*, is determined as: $S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r$ (3)

where,

m = potential mode shift

$Pop_{0.25}$ = population residing and impacted within *quarter-mile* distance of the project

$Pop_{0.50}$ = population residing and impacted within *half-mile* distance of the project

D_{align} = alignment of the project with the funding program, where, 1= indicates alignment and 0 = indicates non-alignment

and,

P_r = probability of the project yielding the expected benefits or output in terms of the quantified metric.

Note: Range for the score, S: -1 to 1

Criterion 2: Vehicle Miles Travelled (VMT)

VMT represents all the miles driven by all the cars and trucks on all the roadways in a region.

$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r$ (4)

m = VMT reduction (in %)

$Pop_{0.25}$ = population residing and impacted within *quarter-mile* distance of the project

$Pop_{0.50}$ = population residing and impacted within *half-mile* distance of the project

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102 Bahbouh, K., Wagner, J. R., Morency, C., & Berdier, C. (2017). Travel demand corridors: Modelling approach and relevance in the planning process. Journal of Transport Geography, 58, 196-208.

103 Wasserman, D., Young, G., Foster, D., Singleton, P. A., & Planning, A. (2022). Mode Shift Potential Evaluations Using Desire Lines & Connections to Active Functional Classification Systems (No. Report No. UT-22.20). Utah Department of Transportation.

D_{align} = alignment of the project with the funding program, where, 1= indicates alignment and 0 = indicates non-alignment
and,
P_r = probability of the project yielding the expected percentage reduction in VMT

Note: Range for the score, S: -1 to 1

Criterion 3: Zero Emission Charging & Fueling Infrastructure/Expand Zero Emission Vehicle Infrastructure

The metric score, *S*, is calculated as follows:

$$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r \qquad (5)$$

m = percentage increase in the electric vehicle miles traveled, number of EV charging points, EV dwell times near charging stations and/or connectivity of EV infrastructure in terms of charging points.
$Pop_{0.25}$ = population residing and impacted within *quarter-mile* distance of the project
$Pop_{0.50}$ = population residing and impacted within *half-mile* distance of the project
D_{align} = alignment of the project with the funding program, where, 1= indicates alignment and 0 = indicates non-alignment
and,
P_r = probability of the project yielding the expected percentage increase in the electric vehicle miles traveled, number of EV charging points, EV dwell times near charging stations and/or connectivity of EV infrastructure in terms of charging points.

Note: Range for the score, S: -1 to 1

Criterion 4: Improve Safety

Reductions in fatalities and crashes is a commonly used measure and metric for safety in project evaluation. The score, *S*, for the criterion is expressed as:

$$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r \qquad (6)$$

m = percentage reductions in fatalities and crashes due to a project evaluated for safety.
$Pop_{0.25}$ = population residing and impacted within *quarter-mile* distance of the project
$Pop_{0.50}$ = population residing and impacted within *half-mile* distance of the project
D_{align} = alignment of the project with the funding program, where 1= indicates alignment and 0 = indicates non-alignment
and,
P_r = probability of the project yielding the expected percentage reduction in fatalities and crashes.

Note: Range for the score, S: -1 to 1

Criterion 5: Climate Adaptation and Resiliency/Address Climate Change

Various measures/metrics that are quantifiable can be used for the criterion of climate adaptation and resiliency. The metrics include evacuation route connectivity, safety, protecting population exposed to extreme weather events, access to transit during extreme events etc. The score, *S*, for the criterion is expressed as:

$$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r \qquad (7)$$

m = percentage improvement in connectivity, safety and access to transit from project evaluated for climate adaptation and resiliency
$Pop_{0.25}$ = population residing and impacted within *quarter-mile* distance of the project
$Pop_{0.50}$ = population residing and impacted within *half-mile* distance of the project
D_{align} = alignment of the project with the funding program, where 1= indicates alignment and 0 = indicates non-alignment
and,
P_r = probability of the project yielding the expected percentage improvement in climate adaptation and resiliency measures and metrics.

Note: Range for the score, S: -1 to 1

Criterion 6: Natural Resources and Ecosystems/Natural and Working Lands

The primary measure/metric is the land consumption that accounts for the acreage of sensitive land that the project consumes or affects. The score, *S*, for the criterion is expressed as:

$$S = 1 - m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r \qquad (8)$$

m = percentage sensitive land affected due to the project
$Pop_{0.25}$ = population residing and impacted within *quarter-mile* distance of the project
$Pop_{0.50}$ = population residing and impacted within *half-mile* distance of the project
D_{align} = alignment of the project with the funding program, where 1= indicates alignment and 0 = indicates non-alignment
and,
P_r = probability of the project expected to consume or affect a certain percentage of sensitive land.

Notes: Range for the score, S: 0 to 1

Criterion 7: Infill Development

Infill development criterion measures/metrics typically include various indices of mixed use, densities, land use diversity etc. The score, *S*, for the criterion is expressed as:

$$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r \qquad (9)$$

m = percentage increase in the mixed use, densities, land use diversity etc. due to the project
$Pop_{0.25}$ = population residing and impacted within *quarter-mile* distance of the project
$Pop_{0.50}$ = population residing and impacted within *half-mile* distance of the project
D_{align} = alignment of the project with the funding program, where 1= indicates alignment and 0 = indicates non-alignment
and,
P_r = probability of the project expected to increase the percentage of mixed use, densities, land use diversity etc.

Note: Range for the score, S: -1 to 1

Criterion 8: Freight Benefit - Throughput, Velocity, and Reliability

Commonly used measure for freight benefit criterion includes annual average daily truck traffic (AADTT) for throughput, average speed or the 85th percentile speed and truck travel time reliability. The score, *S*, for the criterion is expressed as:

$$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r \qquad (10)$$

m = percentage increase in freight benefits due to the project assessed through the measures/metrics such as truck travel time reliability, throughput etc.
$Pop_{0.25}$ = population residing and impacted within *quarter-mile* distance of the project
$Pop_{0.50}$ = population residing and impacted within *half-mile* distance of the project
D_{align} = alignment of the project with the funding program, where 1= indicates alignment and 0 = indicates non-alignment
and,
P_r = probability of the project expected to increase the percentage in freight benefits assessed through the measures/metrics such as truck travel time reliability, throughput etc.

Note: Range for the score, S: -1 to 1

Criterion 9: Congestion Relief

Measures and metrics include mobility, congestion index, reliability, accessibility, delay, etc. Metrics are typically the clearance time, on-time arrival for a trip, percentage of person-miles traveled, etc. The score, *S*, for the criterion is expressed as:

$$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r \qquad (11)$$

m = percentage decrease in mobility, congestion index etc. due to the project
$Pop_{0.25}$ = population residing and impacted within *quarter-mile* distance of the project
$Pop_{0.50}$ = population residing and impacted within *half-mile* distance of the project
D_{align} = alignment of the project with the funding program, where 1= indicates alignment and 0 = indicates non-alignment
and,
P_r = probability of the project expected to decrease congestion-related measures/metrics

Note: Range for the score, S: -1 to 1

Criterion 10: Public Engagement

The most important measure/metric is the public participation level in percentage. The score, *S*, for the criterion is expressed as:

$$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r \qquad (12)$$

m = public participation percentage for the project
$Pop_{0.25}$ = population residing and impacted within *quarter-mile* distance of the project
$Pop_{0.50}$ = population residing and impacted within *half-mile* distance of the project

D_{align} = alignment of the project with the funding program, where 1= indicates alignment and 0 = indicates non-alignment
and,
P_r = probability of the project expected to cause certain percentage of public participation level.

Note: Range for the score, S: -1 to 1

Criterion 11: Benefits to Disadvantaged Communities

A variety of measures/metrics (as indicators) can be used for assessing a project's benefits to disadvantaged communities. These include residents from disadvantaged communities having access to destinations (such as jobs), decrease in traffic exposure or decrease in AADT, cost of travel (i.e. affordability), and inclusivity. The score, *S*, for the criterion is expressed as:

$$S = m \times \left(\frac{Pop_{0.25}}{Pop_{0.50}}\right) \times D_{align} \times P_r \qquad (13)$$

m = percentage increase in access, decrease in traffic exposure etc. for residents in disadvantaged communities
$Pop_{0.25}$ = population residing and impacted within *quarter-mile* distance of the project
$Pop_{0.50}$ = population residing and impacted within *half-mile* distance of the project
D_{align} = alignment of the project with the funding program, where 1= indicates alignment and 0 = indicates non-alignment
and,
P_r = probability of the project expected to cause certain percentage increase in access, decrease in traffic exposure etc. for residents in disadvantaged communities.

Note: Range for the score, S: -1 to 1

Assigning Criteria Weights: Analytical Hierarchy Process (AHP)

Project nomination and evaluation can involve analyzing multiple criteria in which weighing one criterion with another becomes essential. A commonly used methodology for this purpose is the Analytical Hierarchy Process (AHP) – which is widely used by practitioners because of its scientific approach ([104]).

The AHP can be used to assign relative weights to criteria and involves weighting as per the following steps:

Step 1: A pairwise comparison matrix is constructed
Step 2: Eigenvector values, as relative criteria weights, are estimated, and
Step 3. Consistency checks are done.

The steps noted above are described in detail as follows:

Step 1: Pairwise comparisons of two criteria (*i* and *j*) is carried out. A reciprocal matrix (A) is subsequently created, as shown below:

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} \qquad (14)$$

where,

a_{ij} is the decision-maker's quantified judgment of the relative importance of two criteria *i* and *j* . The relative importance is based on the scale of 1 to 9 (see Table 1). The diagonal elements of the matrix A are unity indicating comparison of a criterion with itself. The elements of the lower triangular matrix is the reciprocal of the elements in the upper triangular matrix.

n = total number of performance criteria to be evaluated

Table 1 Ratios for Pairwise Comparison Matrix

Comparison	*X/Y Ratio*
Criterion X is extremely more important than criterion Y	9
Criterion X is strongly more important than criterion Y	7
Criterion X is moderately more important than criterion Y	5

[104] Sinha, K. C., & Labi, S. (2011). Transportation decision making: Principles of project evaluation and programming. John Wiley & Sons.

Criterion X is slightly more important than criterion Y	3
Criterion X is equally important to criterion Y	1
Criterion X is slightly less important than criterion Y	1/3
Criterion X is moderately less important than criterion Y	1/5
Criterion X is strongly less important than criterion Y	1/7
Criterion X is extremely less important than criterion Y	1/9

Each element of the matrix is expressed using the ratio of weights as:

$(w_i/w_j) = a_{ij}$ for $i, j = 1,2, \ldots, n$ (15)

where, w_i and w_j are the relative weights of the pair of performance criteria *i* and *j*, respectively, and *n* is the total number of performance criteria.

The vector **w** = [w_1 w_2 … w_n] represents the weights for the performance criteria and the following matrix relationship is developed:

$$\boldsymbol{Aw} = \boldsymbol{\lambda_{max}} \left(\frac{\boldsymbol{w}}{\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} w_i} \right) \quad (16)$$

where, λ_{max} is the largest eigenvalue and **w** is the eigenvector that corresponds to λ_{max}. Furthermore, a consistency check is carried out to assess the degree of randomness in the judgments used to develop the reciprocal matrix. Consistency check is done using a consistency ratio (CR), as shown below:

$$CR = \frac{\lambda_{max} - n}{(n-1)RI} \quad (17)$$

A CR of 0.1 or lower is considered acceptable. If the CR exceeds 0.1, the reciprocal matrix should be recomputed with updated values for elements of the comparison matrix. Table 2 provides values of RI as reference.

Table 2: Random index (RI) for order of matrix

Order of Matrix (n)	**Average Random Index (RI)**
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Example

Use AHP to assign relative weights to five key criteria for a project:

1. Mode shift
2. VMT
3. Public engagement
4. Benefits to disadvantaged communities
5. Improve safety

Table 3: Pairwise comparison matrix with five criteria used as example (refer Table 1 for the ratios)

	Mode shift	*VMT*	*Public engagement*	*Benefits to disadvantaged communities*	*Improve safety*
Mode shift	1	3	5	7	1/9
VMT		1	3	5	1/9
Public engagement			1	1/5	1/9
Benefits to disadvantaged communities				1	1/9
Improve safety					1

The matrix in Table 3 is used to determine relative weights of the criteria using the AHP. Step 1: Reciprocal matrix ($\boldsymbol{A}$) is constructed from Table 3, along with column sums, as follows:

	Mode shift	*VMT*	*Public engagement*	*Benefits to disadvantaged communities*	*Improve safety*
Mode shift	1	3	5	7	0.11
VMT	0.33	1	3	5	0.11
Public engagement	0.20	0.33	0.20	1.00	0.11
Benefits to disadvantaged communities	0.14	0.20	1.00	1.00	0.11
Improve safety	9.00	9.00	9.00	9.00	1.00
SUM	**10.67**	**13.53**	**18.20**	**23.00**	**1.44**

Step 2: Reciprocal matrix is further expanded from Step 1 table.

	Mode shift	***VMT***	***Public engagement***	***Benefits to disadvantaged communities***	***Improve safety***	***Column Entries Divided by Corresponding Column Sums***					***Row Sums of Last 5 Columns***	***Normalized Weights***
Mode shift	1	3	5	7	0.11	0.09 (=1/10.67)	0.22	0.27	0.30	0.08	0.97	0.19
VMT	0.33	1	3	5	0.11	0.03 (=0.33/10.67)	0.07	0.16	0.22	0.08	0.56	0.11
Public engagement	0.20	0.33	0.20	1.00	0.11	0.02	0.02	0.01	0.04	0.08	0.17	0.03
Benefits to disadvantaged communities	0.14	0.20	1.00	1.00	0.11	0.01	0.01	0.05	0.04	0.08	0.20	0.04
Improve safety	9.00	9.00	9.00	9.00	1.00	0.84	0.67	0.49	0.39	0.69	3.09	0.62
	10.67	**13.53**	**18.20**	**23.00**	**1.44**					Sum =	5	

Step 3: Computations for Consistency Ratios

	Weights	Aw^T (where A is the reciprocal matrix of Step 1)	*Weighted Row Sum*
Mode shift	0.19	1.06	5.46
VMT	0.11	0.55	4.91
Public engagement	0.03	0.19	5.51
Benefits to disadvantaged communities	0.04	0.19	4.77
Improve safety	0.62	4.06	6.58

The consistency ratio (CR) is then determined by first calculating $\boldsymbol{\lambda_{max}}$ as follows :

$$\boldsymbol{\lambda_{max}} = \frac{\mathbf{5.46+4.91+\cdots+6.58}}{\mathbf{5}} = \mathbf{5.45} \tag{18}$$

From Table 2, the random index (RI) = 1.12

$$CR = \frac{\lambda_{max}-n}{(n-1)RI} = \frac{5.45-5}{(5-1)\times 1.12} = 0.099 \ < 0.1 \tag{19}$$

With CR less than 0.1, the weights are acceptable and are summarized as:

Criteria (considered in this example)	***Recommended weights***
Mode shift	0.19
VMT	0.11
Public engagement	0.03
Benefits to disadvantaged communities	0.04
Improve safety	0.62

Finally, the project's overall score, M =

$$\begin{cases} \text{Metric score } S \text{ for Mode shift } \times\ 0.19 \\ + \text{ Metric score } S \text{ for VMT } \times\ 0.11 + \\ + \text{ Metric score } S \text{ for Public engagement } \times\ 0.03 \\ + \text{ Metric score } S \text{ for Benefits to disadvantaged communities } \times\ 0.04 \\ + \text{ Metric score } S \text{ for Improve safety } \times\ 0.62 \end{cases}$$

Note: Range for the score, S: -1 to 1