STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION

TECHNICAL REPORT DOCUMENTATION PAGE

DRISI-2011 (REV 10/1998)

1. REPORT NUMBER	2. GOVERNMENT ASSOCIATION NUMBER	3. RECIPIENT'S CATALOG NUMBER
CA19-3151		

4. TITLE AND SUBTITLE	5. REPORT DATE
Quantifying Results of Key Transit Investments	07/08/2019
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR Shailesh Chandra and Vahid Balali	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS California State University, Long Beach 6300 State University Drive Long Beach, CA 90815	10. WORK UNIT NUMBER 11. CONTRACT OR GRANT NUMBER 65A0710
12. SPONSORING AGENCY AND ADDRESS California Department of Transportation Division of Research, Innovation, and System Information MS-83	13. TYPE OF REPORT AND PERIOD COVERED Final Report 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Caltrans Division of Rail and Mass Transportation (DRMT) administers several public transportation programs in California from the state as well as federal funding sources. There is a need for DRMT management and staff to be able to analyze expenditures on projects that it administers for the state and federal public transportation programs. In order to address this need, appropriate measures and metrics should be identified for projects. The metrics should be quantifiable, measurable, and comprehensible. Under current practices, this is seldom done due to lack of a tool or guidance for DRMT to follow or use.

This research identifies measures and metrics that are quantified for various key project investments and describes appropriate approaches to quantifying identified measures for some sample projects.

17. KEYWORDS	18. DISTRIBUTION STATEMENT	
Transit; bus; funding; metrics; investment	No Restrictions	
19. SECURITY CLASSIFICATION (*of this report*)	20. NUMBER OF PAGES	21. COST OF REPORT CHARGED
Unclassified	98	

DISCLAIMER STATEMENT

Contract No.: 65A0710

Task No. 3151

Quantifying Results of Key Transit Investments

Prepared by:

Shailesh Chandra and Vahid Balali

California State University, Long Beach

July 8, 2019

DISCLAIMER

ACKNOWLEDGEMENT

The authors would like to thank the panel members for providing valuable insights and feedbacks on various aspects of this research. The authors would also like to mention that the support of this research was provided by a contract from Caltrans to California State University, Long Beach.

Table of Contents

This page is left blank intentionally

EXECUTIVE SUMMARY

Caltrans Division of Rail and Mass Transportation (DRMT) administers several public transportation programs in California from the state as well as federal funding sources. There is a need for DRMT management and staff to be able to analyze expenditures on projects that it administers for the state and federal public transportation programs. In order to address this need, appropriate measures and metrics should be identified for projects. The metrics should be quantifiable, measurable, and comprehensible. Under current practices, this is seldom done due to lack of a tool or guidance for DRMT to follow or use.

This research identifies measures and metrics that are quantified for various key project investments and also describes appropriate approaches to quantifying identified measures for some sample projects. Based on the preliminary investigation, there were ten measures identified to determine the project-level impact of specific investments across various transit agencies in California. These measures are accessibility, costs, greenhouse gas (GHG) emissions, land use, mobility, safety and security, service quality, travel time, economic development, and resource utilization.

Seven sample projects along with reports and referenced webpages provided by DRMT were reviewed in this research. Additional project-specific investment results were also collected based on resources collected through web searches. The list of projects that formed the focus of this research is as follows:

1. Project A - Purchase Replacement Transit Vehicles
2. Project B - Redlands Passenger Rail
3. Project C - Rt 34 Fifth St - Rice Avenue Grade Separation
4. Project D - San Onofre to Pulgas Double Track Phase 2
5. Project E - Shafter Saturday DAR Service
6. Project F - Clipper Fare Payment System
7. Project G - Purchase 29 -45' Buses

The research findings have been limited to assessing only short-term impacts of the project investments – i.e. immediately after the project is completed and the facility becomes functional. Assessment of long-term impacts of each investment will involve in-depth study and inclusion of various other factor determined through surveys and interviews from various stakeholders.

The quantified outcomes are estimated using percentage change for a metric under each measure ‘before’ and immediately ‘after’ the project investment. This helps in normalizing the outcomes (or, results) across a variety of metrics under the same performance measure.

For each project, a decision matrix was developed based on the findings of various outcomes of the quantified measures. The matrix shows that the data and information available for Project D - San Onofre to Pulgas Double Track Phase 2 was enough to quantify half of the measures, namely – accessibility, costs, GHG emissions, mobility, travel time and resource utilization. For other projects, at most two measures could be quantified.

When compared for measures across projects, Project B - Redlands Passenger Rail (scheduled for a future date completion) will have very high accessibility and mobility increase. This is expected as a completely new passenger rail line will be operational with the project completion. The project connects five key stations in the San Bernardino County. Project D - San Onofre to Pulgas Double Track Phase 2 will have the second highest percentage increase in accessibility.

Project G - Purchase 29 -45' Buses has the highest cost percentage reduction while Project A - Purchase Replacement Transit Vehicles has the least percentage decrease in cost measure.

Project E - Shafter Saturday DAR Service has the highest percentage GHG emission reduction while Project D - San Onofre to Pulgas Double Track Phase 2 has the lowest percentage reduction.

For the mobility impacts, Project F - Clipper Fare Payment System has the lowest quantified increase – whereas Project B - Redlands Passenger Rail has the largest percentage mobility increase.

Project C - Rt 34 Fifth St - Rice Avenue Grade Separation and Project D - San Onofre to Pulgas Double Track Phase 2 – both scheduled for future date completion - would have an almost similar percentage decrease in travel time.

Due to limitations in project-specific data, the resource utilization of only Project D - San Onofre to Pulgas Double Track Phase 2 could be calculated. A percentage increase in resource utilization is expected from this project.

Project reviews show that Caltrans should measure outcomes that can be directly quantified - defined as ‘active’ measures. Measures that cannot be directly quantified or estimated can be categorized into ‘passive’ measures. In addition, measures that can be classified as ‘active’ measures consist of those that are at the immediate geographical vicinity of the project. ‘Passive’ measures are those that have no fixed geographical boundaries that can be defined for their measurement - but are very important. Further, both ‘short-term’ and ‘long-term’ benefits resulting from a project should be tracked. A short-term assessment of measures could be after a day, a week, a month, a year or a few years after the project completion date. A long-term assessment of measures is usually after ten years of project completion. The determination of long-term projects can also be in the number of years that could be defined by stakeholders of the project.

Based on this research, it is recommended that the assessment period (whether short-term or long-term) of a project should be defined when quantifying results of investments. This should be followed by defining appropriate measures for the assessment period considered for the quantification.

This page is left blank intentionally

INTRODUCTION AND BACKGROUND

Caltrans Division of Rail and Mass Transportation (DRMT) administers several public transportation programs both from the state as well as federal funding sources. The functional and organizational structure of DRMT consists of five offices, which are: - (i) Program Management (ii) Project Development, Management, and Delivery (iii) Rail Planning and Operations (iv)Transit Grants and Contracts, and (v) Rail Equipment. DRMT plans and develops intercity rail capital projects and highway/railroad crossing improvements; it also supports and coordinates California's rail and mass transportation systems.

There is a need for DRMT management and staff to be able to analyze expenditures on projects that it administers for the state and federal public transportation programs. In order to address this need, appropriate measures and metrics should be identified for projects. The metrics should be quantifiable, measurable, and comprehensible. Under current practices, this is seldom done due to lack of a tool or guidance for DRMT to follow or use. This research identifies measures that are quantified for various key project investments.

Based on the preliminary investigation, there were primarily ten key measures that were used to determine the project-level impact of specific investments across various transit agencies in California. These measures are accessibility, costs, greenhouse gas (GHG) emissions, land use, mobility, safety and security, service quality, travel time, economic development, and resource utilization[1].

LITERATURE REVIEW

Literature review shows that there are two primary forms of impacts related to transit investments: (i) impacts on the economy, which encompass effects on jobs and income, and (ii) economic valuation of broader societal benefits, which encompass the valuation of "non-user benefits" (affecting quality of life, environment, and productivity) in addition to user benefits[2]. However, these impacts are dependent on basic outputs – both measurable and non-measurable - that are key in decision-making for investments such as travel time and cost savings. Based on literature reviews, state of practice for assessing economic benefits and impacts of transit investments and in project selection, the following eight topics often serve as a guidance:

1. Scope of study of the projects, time frame for a given scope of study and frequency of responses from transit users for the following:
    - The entire transit system
    - A line of subsystem
    - An individual site or station

---

[1] Resource utilization is defined as a means for transit agencies to reduce costs and other operational expenditures for fleet.

[2] Transit Cooperative Research Program (TCRP) Synthesis Report 128: Practices for Evaluating the Economic Impacts and Benefits of Transit, 2017.

2. Time frame of the project
    - Past investment
    - Existing operations
    - Future scenario

3. Type of project
    - Spending effects of construction and/or operations
    - Performance effects of transit service and investments

4. Impacts assessed
    - The value of traveler benefits (e.g., travel time, cost, safety)
    - The value of environmental and/or community benefits
    - The wider effects in the economy (e.g., jobs, GDP, wages, or sales)

5. Motivations for assessment
    - Public information
    - Making the case for funding
    - Long-term planning
    - Project prioritization
    - Evaluation of project alternatives
    - Evaluation of prior investments

6. Frequency of economic studies
    - Regularly (e.g. every few years or evaluating every major project)
    - Special situations or special types of projects

7. Tools or methods used
    - Travel demand or traffic network model
    - Direct surveys or interviews
    - Direct on-site observations
    - Comparison to case studies elsewhere
    - Statistical/regression analysis
    - Static input/output models
    - Economic simulation models
    - Custom spreadsheet tools
    - Focus groups
    - Cost-benefit analysis

8. Measures used to represent economic value
    - Effect on employment (jobs)
    - Effect on personal income
    - Effect on economic activity (value added/GRP)
    - Effect on business sales (output)

- Effect on property values and development
- Economic value of societal benefit
- Other (specify)

Performance Measures and Metrics

Based on key literature surveys, a list of performance measures and corresponding metrics (particularly those that reflect outcomes of indirect and direct investments) have been compiled in Table 1. These ten measures consisting of accessibility, costs, greenhouse gas (GHG) emissions, land use, mobility, safety and security, service quality, travel time, economic development, and resource utilization are widely used in assessing transit investment impacts of rail and mass transportation ([3],[4],[5],[6],[7],[8],[9]).

Table 1: Compilation of key performance measures and metrics used in transit investment decision-making and planning

	Measure	***Metric***
1	*Accessibility*	• Meeting requirements of the Americans with Disabilities Act (ADA) such as compliance and coverage of transit services (for example, distance between stops and proximity to disadvantaged communities). • Number of vehicles purchased being ADA-compliant • Difference in total number of riders served before and after the project • Increase in stop-level accessibility • Ridership and boarding counts along the route (before and after the project) • Determine stop productivity • Number of stations by ADA accessibility • Coverage:

[3] Performance Metrics for the Evaluation of Transportation Programs, National Transportation Policy Project, 2009.
[4] Transit Cooperative Research Program (TCRP) Report 141: A Methodology for Performance Measurement and Peer Comparison in the Public Transportation Industry, 2010.
[5] Litman, T., 2015. Evaluating public transit benefits and costs. British Columbia, Canada: Victoria Transport Policy Institute.
[6] Establishing a Framework for Transit and Rail Performance Measures, Division of Transit and Rail, Colorado Department of Transportation, December 2012.
[7] Rodier, C. and Issac, E., (2016). Transit Performance Measures in California, Mineta Transportation Institute, MTI Report 12-58.
[8] Transit Cooperative Research Program (TCRP) Report 176: Quantifying Transit's Impact on GHG Emissions and Energy Use—The Land Use Component, 2015.
[9] Quantifying the Results of Key Transit Investments, Preliminary Investigation, Caltrans Division of Research, Innovation and System Information, 2018.

		▪ Ability to reach goods, services, and activities (coverage of transit services) ▪ Percentage of population within given miles of transit ▪ Percentage of population within given miles of transit stations ▪ Percentage of rural counties with public transit service • Population served: ▪ Percentage of rural population with transit service ▪ Percentage of transit-dependent population with transit service available ▪ Percentage of transit stops that are ADA compliant ▪ Percentage of residents, major employers and schools served within one-quarter mile of a transit stop. • Connectivity: ▪ Number of transit stops ▪ Number of intermodal stations ▪ Number of communities connected
2	*Costs*	• Changes in operating costs • Asset life cost • Cost per revenue hour • Capital budget and expenditures • Operating cost per revenue hour • Operating cost per revenue mile • Opportunity cost per passenger • Maintenance cost as a percentage of operating costs • Labor cost per vehicle hour • Vehicle miles (hours) per revenue mile (hour) • Operating cost per peak vehicle in service • Farebox recovery ratio • Operating cost per boarding • Operating cost per passenger-mile • Operating cost per service area capita • Cost per trip (or PMT, VMT, revenue-mile, passenger-mile) • Number of vehicle system failures • Maintenance category cost/total maintenance cost • Average annual maintenance cost per vehicle operated in maximum service • Vehicle maintenance cost/vehicle (car) mile • Maintenance full-time equivalents (FTEs)/vehicle operated in maximum service • Non-vehicle maintenance cost/track mile

3	*Greenhouse Gas (GHG) Emissions (and other pollutants)*	• GHG emissions for zero-emissions buses and diesel fleets. • Metrics under the Low Carbon Transit Operations Program (LCTOP) semiannual reporting requirements • Estimate emissions associated with land use and development • Engine size or type to provide guidance on vehicle purchases that would assist in lowering GHG emissions. • Fuel type of new versus displaced vehicles to assess reductions in GHG emissions • Increase in alternative-fuel bus fleet • Changes in service miles, hours and the amount of fuel consumed on an annual basis • Vehicle fuel efficiency based on mile per gallon
4	*Land Use*	• Geographical dispersion • Area compatibility for transit projects
5	*Mobility*	• Expansion of the transit fleet or transit network • Changes in ridership and boardings • Changes in passenger trips for a project (route and service) • Effectiveness of mobility and service connections • Quality of Service ▪ Frequency – Number of transit trips daily (on a typical weekday, Saturday, Sunday) ▪ Frequency – Number of passenger rail trips daily (on a typical weekday, Saturday, Sunday) ▪ Frequency – Number of transit service hours daily (on a typical weekday, Saturday, Sunday) ▪ Frequency - Number of transit service days annually ▪ Connectivity – Number of timed-transfer stops between intercity passenger rail and local bus transit service ▪ Reliability – Percentage of transit trips on time ▪ Reliability – Percentage of passenger rail trips on time ▪ Percent of fleet with (wi-fi, on-board restrooms, etc.) ▪ Percent of transit stations with (indoor waiting areas, vending machines, restrooms, etc.) ▪ Percent of agencies using real-time passenger information systems • Mode Share ▪ Passenger-miles on transit bus (percentage or number) ▪ Passenger-miles on rail transit (percentage or number)

		▪ Total passenger-miles on transit (percentage or number)
6	*Safety and Security*	• Safe entry and departure of vehicles and passengers • Safety and security measures • Key performance indicators (KPIs) related to safety such as preventable accidents • Operator safety in terms of traffic level, lighting, and other factors • Number of accident reports and problem road calls • Traffic level, lighting, and other factors • Incidents ▪ Number of incidents (per VMT, per Year, per 1,000 passenger trips) (by severity) ▪ Number of incidents at at-grade rail crossings • Facility ▪ Percentage of rolling stock with safety features (driver cam, passenger cams, equipment, etc.) ▪ Percentage of at-grade crossings with active warning protection • Security ▪ Percentage of transit bus stops/ transfer points/stations with security features such as lighting, security staff, or CCTV ▪ Percentage of passenger rail stops/transfer points/stations with security features such as lighting, security staff, or CCTV ▪ Percentage of facilities that meet FTA security guidelines • Casualty and liability cost per vehicle mile
7	*Service Quality*	• Project's ability to offer increased services and provide on-time performance • Rider satisfaction with service quality • Mean distance between failures, on-time performance, and number of complaints • Complaint statistics on rider satisfaction • On-time performance • Schedule adherence • Average system speed • On-time performance • Excess wait time • Passenger loading

		• Overall satisfaction • Number of complaints per 1,000 boardings • Number of compliments per 1,000 boardings • Call-center response time • Missed trips • Service span • Average system peak headway • Revenue miles per urban area sq. mi • Revenue miles (hours) per capita • Percent of fleet with ramps/low-floor
8	*Transit Ridership*	Ridership by route, program, and system
9	*Economic Development*	• Employment ▪ Workers employed by transit agencies ▪ Number/Percentage of jobs/businesses served by transit
10	*Resource Utilization*	• Vehicle hours per vehicle operated in peak service • Vehicle miles per vehicle operated in peak service • Revenue hours per employee full-time equivalent • Vehicle miles per gallon of fuel consumed • Vehicle miles per kilowatt-hour of power consumed • Revenue hours per vehicle operated in peak service • Revenue miles per vehicle operated in peak service • Peak-to-base ratio

RESEARCH FINDINGS ON QUANTIFYING RESULTS OF INVESTMENTS

Seven sample projects along with reports and referenced webpages provided by DRMT were reviewed in this research. Additional project-specific investment results were also collected based on resources collected through web searches. The list of projects that formed the focus of this research is as follows:

1. Project A - Purchase Replacement Transit Vehicles
2. Project B - Redlands Passenger Rail
3. Project C - Rt 34 Fifth St - Rice Avenue Grade Separation
4. Project D - San Onofre to Pulgas Double Track Phase 2
5. Project E - Shafter Saturday DAR Service
6. Project F - Clipper Fare Payment System
7. Project G - Purchase 29 -45' Buses

The research findings are limited to assessing only short-term impacts of the investments[10] – i.e. immediately after the project is completed. The quantified outcomes are estimated using percentage change for a metric 'before' and immediately 'after' the investment for each project. This helps in normalizing the outcomes (or, results) across a variety of metrics under the same performance measure. The percentage change calculation formula for each metric is shown in the Appendix for each studied measure in this research. The formula expressed in the percentage calculations are also embedded into the spreadsheet tool developed and provided as a supplement to this final report.

PROJECT A - PURCHASE REPLACEMENT TRANSIT VEHICLES

Project Overview

The project involves the purchase of three new buses that add to the existing fixed route fleet for the Beach Cities Transit (BCT) operating in City of Redondo Beach. These three new buses are ADA-compliant and CNG-powered and were put to service between 2012 to 2015. The total investment in the project was $1,305,009. Based on the Final Project Report by City of Redondo Beach[11], the replacement with the three new buses reduced operating/maintenance costs by 8%.

BCT operates two lines – Line 102 and Line 109[12], with service area shown in the maps of Fig. A1 and Fig. A2, respectively. Line 102 service hours are from 6:00 a.m. to

---

[10] Assessment of long-term impacts of each investment will involve in-depth study and inclusion of various other factors determined through surveys and interviews from various stakeholders.

[11] Final Project Report, City of Redondo Beach, accessed on March 21, 2019. https://bondaccountability.dot.ca.gov/CloseoutDocumentViewPreAction.do?reportTypeNbr=1&cmiaproj=10/11-2-20M(001)

[12] Beach Cities Transit, City of Redondo Beach, accessed on March 23, 2019. https://www.redondo.org/depts/recreation/transit/beach_cities_transit/default.asp

8:00 p.m. with 30 to 45-minute headway, and it provides service between the Redondo Beach Pier and the Redondo Beach Green Line Station. The travel time between the two endpoints is around 41 minutes using the transit – covering 7 miles of travel distance.

The service hours of BCT Line 109 is 6:00 a.m. to 10:00 p.m. The transit service has a 40 to 50-minute headway. The service is provided between the stations of Redondo Beach Riviera Village and LAX City Bus Center. The travel time between the two stations, which are the endpoints, is around 77 minutes using the transit (covering almost 22 miles of travel distance).

Emission Analysis

With an assumption that the replaced buses are diesel operated buses, emissions calculations are performed. Emission factors are obtained for urban transit buses for CNG-powered buses and diesel buses from California Air Resources Board (CARB) which are shown in Table A1. These factors are used to calculate total NOx and PM2.5 emissions per trip for the two fuel type buses. The final calculated emission values are shown in Table A2.

Table A1: Emission factors for a bus (Source: CARB, 2018[13])

Urban Transit Bus Fuel Type	Emission Factors (grams per mile)	
	NOx	**PM2.5**
Diesel	1.03	0.0044
CNG	0.80	0.0030

Table A2: Emission for the two fuel type buses

(based on factors from Table A1 and distance traveled by Line 102 and Line 109 in one trip)

Urban Transit Bus Fuel Type	Total Emissions (in grams per trip*)				Total Emissions (in grams per trip)
	NOx		**PM2.5**		
	Line 102	**Line 109**	**Line 102**	**Line 109**	
Diesel	7.2	22.7	0.03	0.097	30
CNG	5.6	17.6	0.02	0.066	23

**Line 102: travel distance of 7 miles for the longest trip, Line 109: travel distance of 22 miles for the longest trip*

Thus, total emissions accounted for diesel and CNG-powered urban transit buses are 30 and 23 grams per trip, respectively. With three diesel-powered bus replacements with CNG-powered buses, the total emissions would decrease from 90 grams per trip to 69 grams per trip.

[13] Emission Factor Tables, March 2018. California Air Resources Board, accessed on March 12, 2019. https://www.arb.ca.gov/planning/tsaq/eval/evaltables.pdf

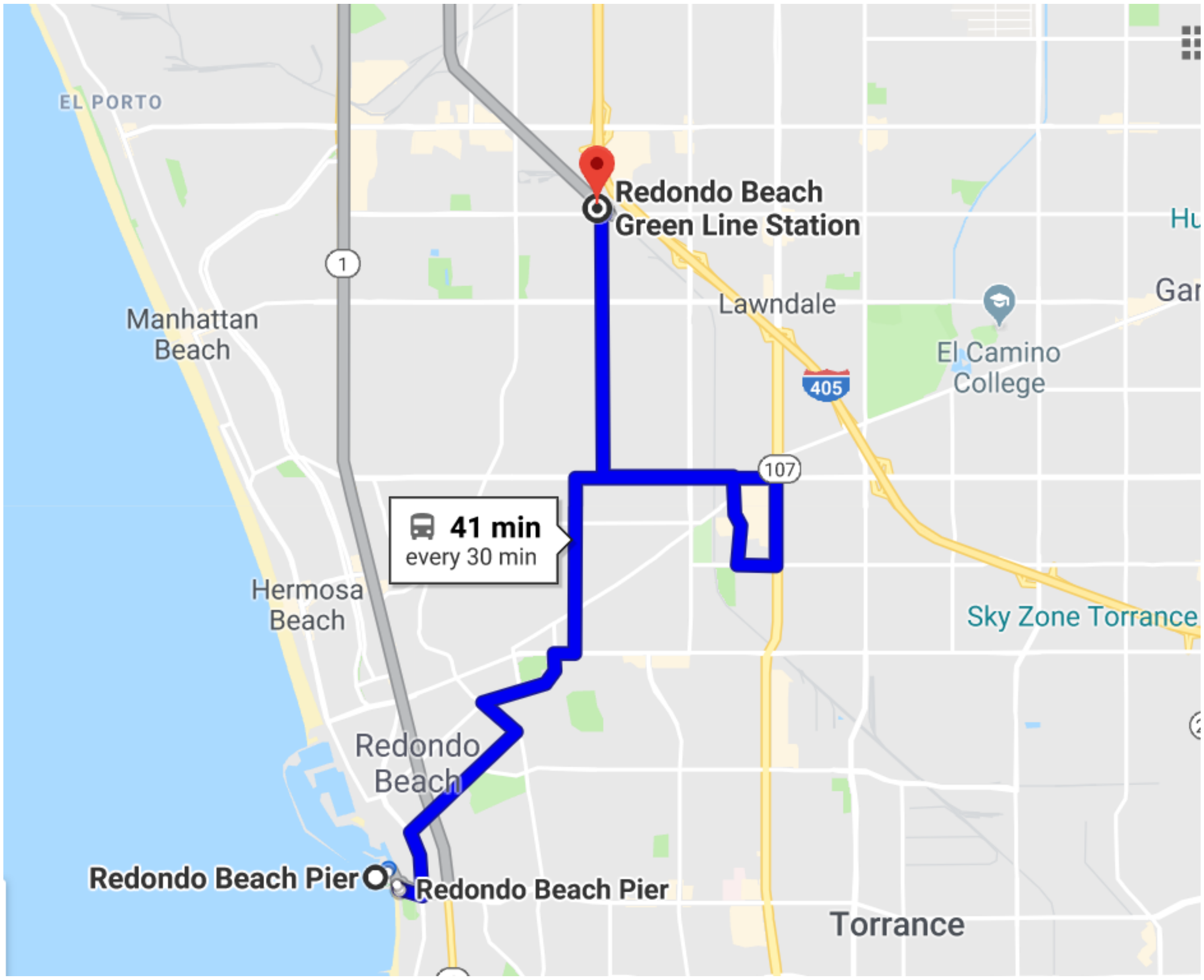

Figure A1: Line 102 service map

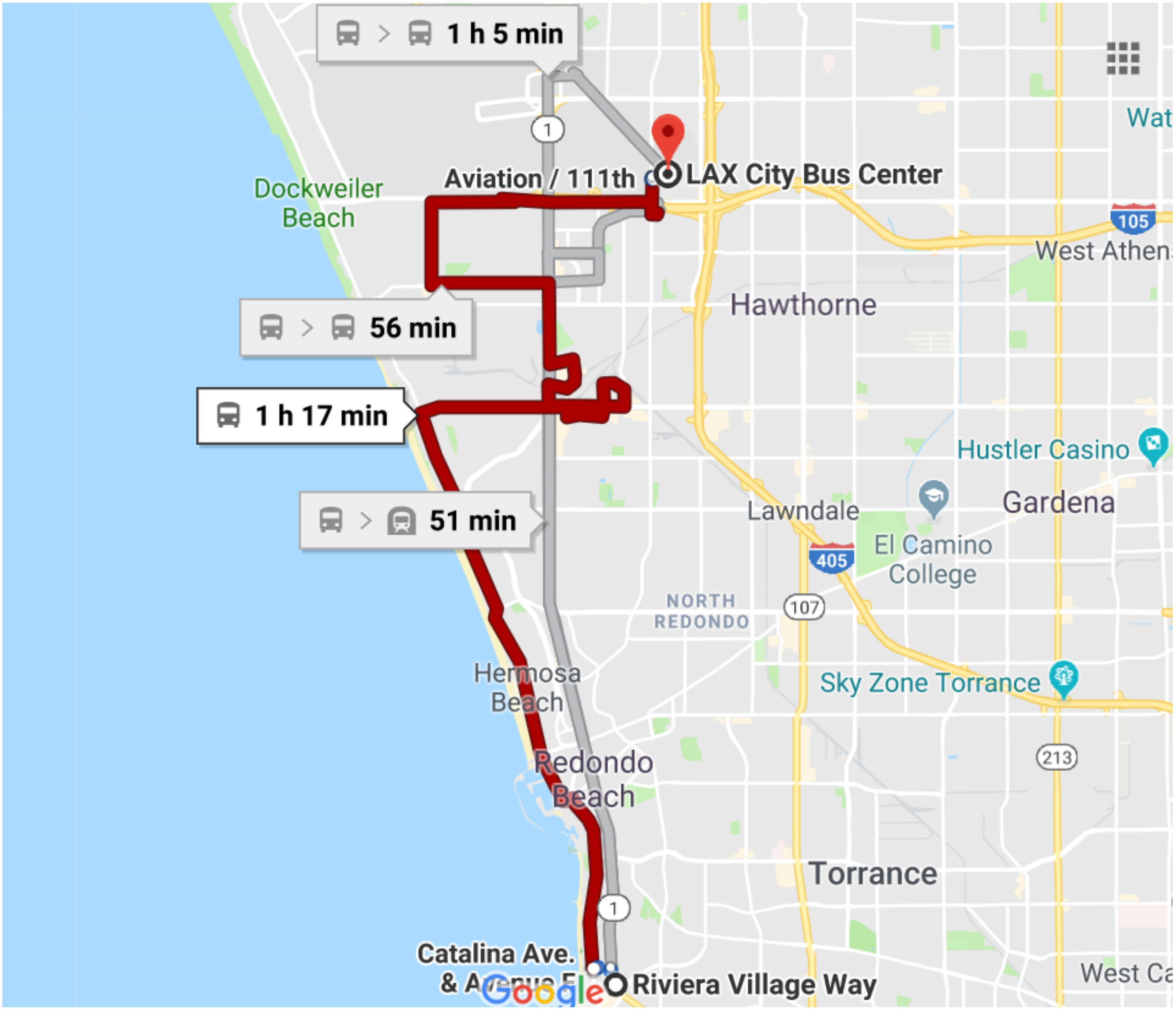

Figure A2: Line 109 service map

Quantification of Outputs

Table A3: Formulation for quantifying cost measure

Measure	*Metric*	*Definition*	*Output Expression*	*% Reduction*
Costs	Operating costs	$Oper_{before}$ = transit operating cost before the improvement/investment $Oper_{after}$ = transit operating cost after the improvement/investment	$Output\ 1 = \left(\frac{Oper_{before} - Oper_{after}}{Oper_{before}}\right) \times 100$	8%

Table A4: Formulation for quantifying greenhouse gas emissions measure

Measure	*Metric*	*Definition*	*Output Expression*	*% Reduction*
Greenhouse Gas (GHG) Emissions (and other criteria pollutants)	GHG emissions for cars and diesel fleets	$GHGemissions_{before}$ = total greenhouse gas emissions reductions (including criteria pollutants) before the improvement/investment = **90 grams per trip** $GHGemissions_{after}$ = total greenhouse gas emissions reductions (including criteria pollutants) after the improvement/investment = **70 grams per trip**	$Output\ 1 = \left(\frac{GHGemissions_{before} - GHGemissions_{after}}{GHGemissions_{before}}\right) \times 100$	22.4%

PROJECT B - REDLANDS PASSENGER RAIL

Project Overview

The project Redlands Passenger Rail is scheduled to be operational in 2021 and has a total project investment of $282,277,000. The project location is in San Bernardino County which will connect the cities of San Bernardino and Redlands. The connectivity will be provided with the construction of 9 miles of track to implement a new passenger rail service. The new passenger rail service will provide stops at four new station locations: Tippecanoe Avenue Station, New York Street Station, Downtown Redlands Station, and the University Station (see Fig. B1). The project is also aimed to provide station improvement to the already existing San Bernardino Transit Center.

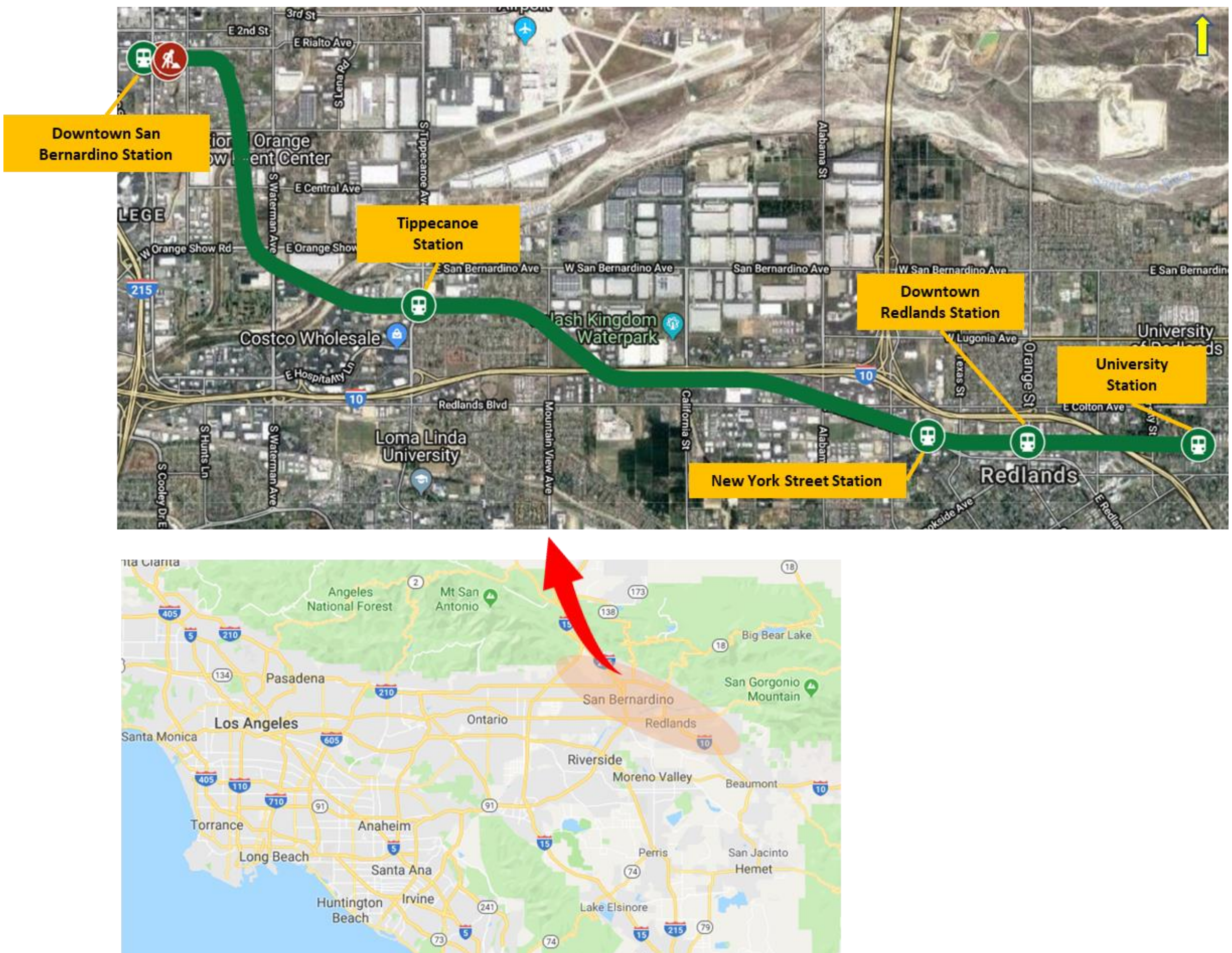

Figure B1: Project location of Redlands Passenger Rail

Quantifying Results – Approach

The project decision has been based on meeting the following purpose and needs[14].

1. *Travel Demand*. Population and employment forecasts show significant growth in southwestern San Bernardino County through 2035, which would impact travel demand in the region in which the rail line lies. The employment growth within San Bernardino and Redlands projected to increase by 22 percent in 2035, and with the population growth being anticipated to increase by 12 percent in San Bernardino and 14 percent in Redlands. Thus, the demand for alternative forms of transportation such as transit will also see a surge.

2. *Transit Performance and Travel Time*. The travel time between Redlands and San Bernardino using an existing bus route varies between 45 to 60 minutes – with the current on-time performance for the service averaging approximately 70%. With the project, transit travel times will be reduced to approximately 17 minutes with the 9-mile rail line. The primary roadway in the region, Interstate-10 (I-10), and other surrounding arterials are often very congested. Thus, the goal of the project will be to improve mobility options, transit reliability, and on-time performance when compared to existing bus transit service or using the existing network of surrounding roads.

3. *Regional connectivity*. Connectivity to the regional Metrolink system and the existing bus and non-motorized transportation network will be provided by the project. Congestion on highways such as I-10 will also be reduced. This will subsequently increase access to major employment centers I-10 connects to the west of the Redlands Corridor in Orange and Los Angeles Counties.

Other specific details of the project are as follows (Source: Redlands Passenger Rail, 2019)[15]:

i) Rail service will operate 30-minute peak and 60-minute off-peak service on weekdays
ii) Service will operate 60-minute service on weekends
iii) Project includes 27 grade crossings, including three new closures and one previous closure
iv) Project includes construction of 7 miles of single track and 2 miles of double track section for the passing of trains

[14] Record of Decision on the Redlands Passenger Rail Project in San Bernardino County, California by the Federal Transit Administration, accessed on March 18, 2019. http://www.gosbcta.com/plans-projects/projects/arrow/RPR-FTA-RecordofDecision.pdf
[15] Redlands Passenger Rail, Local Partnership Program (LPP) and Solutions for Congested Corridors Program (SCCP), State of California – California Transportation Commission, accessed on March 22, 2019.

v) Rail vehicles will consist of self-propelled two-car trainsets
vi) Freight rail speed will increase from 10 mph to 55 mph
vii) Transit travel times will reduce from 45-60 minutes using existing bus routes to approximately 17 minutes using rail
viii) Service forecast is expected to serve 2,100 passengers per day in 2020

Analysis

OmniTrans Trip Planner shows that Route 8 bus connects University of Redlands Station and Downtown San Bernardino. The bus operates every 30 minutes on weekdays and every 60 minutes on Saturdays and Sundays ([16]). Route 8 provides service from around 5 am in the morning till 10 pm in the night during weekdays and around 6 am to 7 pm on Saturday and around 9 am to 7 pm on Sundays ([17]). Thus, almost 34 (=17×60/30) trips occur during weekdays, 13 (=13×60/60) trips on Saturdays, and 10 (=10×60/60) trips on Sundays.

All Omnitrans 40’ vehicles operate using compressed natural gas (CNG) propulsion systems. Route 8, which is a standard 40’ coach, has a seating capacity of around 38 passengers ([18]). Thus, assuming full transit occupancy, the number of passengers using Route 8 on a weekday is 38×34 = 1,292 passengers per day. With service forecast expected to serve 2,100 passengers per day in 2020, the difference of 808 passengers can be assumed to be using other modes of transportation. If all 808 passengers are assumed to be using cars, the emissions reduction have been calculated and shown in Table B2 based on the rates in Table B1. The travel time between University of Redlands Station and Downtown San Bernardino using a car as a mode is approximately 20 mins on a weekday.

Table B1: Input emission rates by type of vehicle, grams per mile per trip[19]

Vehicle Type	VOC	CO	NOx	CO_2
Passenger Cars	1.034	9.400	0.693	368.4

[16] OmniTrans Trip Planner, accessed on March 23, 2019. http://www.omnitrans.org/getting-around/plan-a-trip/trip-planner/
[17] Route 8 Schedule, OmniTrans, accessed on March 22, 2019. http://www.omnitrans.org/upload/marketing-planning/pdf/Route_008_0915.pdf
[18] Transit Design Guidelines, OmniTrans, accessed on March 22, 2019. http://www.omnitrans.org/news-and-resources/plans-reports-and-guidelines/files/Omnitrans-Transit-Design-Guidelines.pdf
[19] Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks, United States Environmental Protection Agency (EPA), Office of Transportation and Air Quality, October 2008. Accessed on May 22, 2019. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100EVXP.TXT. , U.S. Department of Transportation, 2019.

Table B2: Change in passenger car emissions (in grams) per trip

Vehicle Type	VOC	CO	NOx	CO_2
Passenger Cars	16,709 (=1.034×808×20)	151,904 (=9.4×808×20)	11,198 (=0.693×808×20)	5,953,344 (=368×808×20)

Total emission reductions from Table B2 = 16,709 + 151,904+ 11,198 + 5,953,344= 6,133,156 grams = 6.13 metric tons

Quantification of Outputs

Table B3: Formulation for quantifying accessibility measure

Measure	*Metric*	*Definition*	*Output Expression*	*% Increase*
Accessibility	Increase in stop-level accessibility along the route	$StopAccess_{before}$ = population or jobs accessible around stops before the improvement/investment = **(1/60)** considering the worst case scenario with the use of transit buses $StopAccess_{after}$= population or jobs accessible around stops after the improvement/investment = **(1/17)**	$Output\ 1 = \left(\frac{StopAccess_{after} - StopAccess_{before}}{StopAccess_{before}}\right) \times 100$	253%

Table B4: Formulation for quantifying mobility measure

Measure	*Metric*	*Definition*	*Output Expression*	*% Increase*
Mobility	Average speed	$RouteSpeed_{before}$ = average speed on the route before the improvement/investment **= (9×60/60)** – considering 9 miles as a distance of total route **= 9 mph**	$Output\ 1 = \left(\frac{RouteSpeed_{after} - RouteSpeed_{before}}{RouteSpeed_{before}}\right) \times 100$	256%

		$RouteSpeed_{after}$ = average speed on the route after the improvement/investment **= (9×60/17)** – considering 9 miles as a distance of total route **=32 mph**		
	Ridership and boardings	$Ridership_{before}$ = ridership before the improvement/investment **= 1292 per day** $Ridership_{after}$ = ridership after the improvement/investment **= 2100 per day**	$Output\ 1 = \left(\frac{Ridership_{after} - Ridership_{before}}{Ridership_{before}}\right) \times 100$	62.5%

PROJECT C - RT 34 (FIFTH ST)/RICE AVENUE GRADE SEPARATION

Project Overview

The project Rice Avenue with State Route 34 (SR 34) and the Union Pacific Railroad (UPRR) Grade Separation will separate the existing overcrossing, widen from four lanes to six lanes, and install connector roads, signals, and sidewalks. The project location is in the City of Oxnard in the county of Ventura. SR 34 (Fifth Street) is designated as a conventional highway running east-west, and Rice Avenue is an arterial roadway running north-south through the City and the county of Ventura. The project location is shown in the map of Fig.C1.

Figure C1: Location of the project[20]

[20] Rt 34 (Fifth St)/Rice Avenue Grade Separation Report, accessed on March 20, 2019. http://www.catc.ca.gov/programs/sb1/reforms/docs/05_Signed_Baseline_Agreement-TCEP-RiceAvenueandFifthStreetGradeSeparation.pdf

The project has a start date of June 2018 with an end date which is not confirmed yet. The project has a total investment cost of $79,192,000.

Crash Data

As per the Rt 34 (Fifth St)/Rice Avenue Grade Separation Report, the following information has been gathered on accidents:

Average number of accidents (property damages, injuries, and fatalities) per year prior to the project implementation = 12

Average number of accidents (property damages, injuries, and fatalities) per year prior to the project implementation = 0 (best case scenario)

Delay Changes

Existing intersection delay is 81.9 sec for both AM and PM peak hours in 2016. With grade separation, the delay will be 55.1 sec.

Greenhouse Gas (GHG) Emissions and Other Criteria Pollutants

Average daily forecast traffic at the location in 2020 is 53,400 vehicles. The GHG emissions are estimated based on the delay and projected traffic volume data in 2020 (see Table C1).

Table C1: Input emission rates by type of vehicle, grams per minute[21]

Vehicle Type	VOC	CO	NOx	CO_2
Passenger Car	0.0447	1.1871	0.0586	31.0652

Total emissions reductions before grade separation = $(0.0447+1.1871+0.0586+31.0652) \times (81.9/60) \times 53400 \times 10^{-6}$ = 2.4 metric tons

Total emissions reductions after grade separation = $(0.0447+1.1871+0.0586+31.0652) \times (55.1/60) \times 53400 \times 10^{-6}$ = 1.6 metric tons

Fuel Consumption: Table C2 shows the rate of fuel consumption in gallons per minute for a passenger car. Based on the rate in Table C2, the total volume of fuel consumption by vehicles (such as passenger cars) is compiled in Table C3 for the 'with' and 'without' grade separation scenarios.

[21] Emissions per minute are from GradeDec.Net - System for Highway-Rail Grade Crossing Investment Analysis, Federal Railroad Administration, U.S. Department of Transportation, 2019.

Table C2: Rate of Fuel Consumption[22]

Vehicle Type	Fuel gallons/minute
Passenger Car	.00969

Table C3: Per day fuel consumption in gallons

	Total Fuel Consumption (in gallons)	
Vehicle Type	**Without Grade Separation**	**With Grade Separation**
Passenger Car	**706** =0.00969×81.9×(1/60)×53400	**475** =0.00969×55.1×(1/60)×53400

[22] GradeDec.Net reference manual, accessed on March 22, 2019. https://www.fra.dot.gov/Elib/Document/14851.

Quantification of Outputs

Table C4: Formulation for quantifying greenhouse gas emissions measure

Measure	*Metric*	*Definition*	*Output Expression*	*% Reduction*
Greenhouse Gas (GHG) Emissions (and other criteria pollutants)	GHG emissions for cars and diesel fleets	$GHGemissions_{before}$ = total greenhouse gas emissions (including criteria pollutants) before the improvement/investment = **2.4 metric tons** $GHGemissions_{after}$ = total greenhouse gas emissions (including criteria pollutants) after the improvement/investment = **1.6 metric tons**	$Output\ 1 = \left(\frac{GHGemissions_{after} - GHGemissions_{before}}{GHGemissions_{before}}\right) \times 100$	32.7%
	Changes in service miles, hours and the amount of fuel consumed on an annual basis	$FuelConsumed_{before}$ = fuel consumed before the improvement/investment = **706 gallons**	$Output\ 3 = \left(\frac{FuelConsumed_{before} - FuelConsumed_{after}}{FuelConsumed_{before}}\right) \times 100$	32.7%

	(includes diesel engines and trucks)	$FuelConsumed_{after}$ = fuel consumed after the improvement/investment = **475 gallons**		

Table C5: Formulation for quantifying travel time measure

Measure	*Metrics*	*Definition*	*Output Expression*	*% Reduction*
Travel Time	Scheduled travel times changes	$SchedEqui_{before}$ = scheduled travel time before the improvement/investment = 81.9 sec $SchedEqui_{after}$ = scheduled travel time after the improvement/investment = 55.1 sec	$Output\ 1 = \left(\frac{SchedEqui_{before} - SchedEqui_{after}}{SchedEqui_{before}}\right) \times 100$	32.7%

PROJECT D - SAN ONOFRE TO PULGAS DOUBLE TRACK PHASE 2

Project Overview

The project San Onofre to Pulgas Double Track Phase 2 with a total project investment of $30,040,000 is scheduled to be completed by 2020. The project is a reconfiguration of a 1.6-mile single line to a double rail track line on the Los Angeles – San Diego – San Luis Obispo Rail (LOSSAN) corridor. There is an existing double track located both north and south of the proposed project limits. Other project goals are as follows:

- Increase in mainline capacity sufficiently to handle long term Port of San Diego demand, cross border bulk goods movement, and regional demand for heavy bulk commodities, and
- Increase in rail capacity and reliability on the corridor.

Quantifying Results – Approach

Based on NCHRP Report 773[23], grid time analysis is used to determine the upper limit (capacity) for the number of daily trains the corridor can handle after the double line construction. The time it takes a train to travel the distance between two sidings (or stations) and clear the way for an opposing train on a single track section is called the one-way grid time. Figure D1 (along with Figure D2) provides the map and other details of the project location for double track construction.

Currently, Amtrak operates 22 Pacific Surfliner trains per day on weekdays and 24 per day on weekends, the Metrolink commuter services 16 trains per day Monday through Friday, 10 trains per day on Saturday, and 8 trains per day on Sunday. There is a total of 38 passenger trains per day on weekdays and 34 trains per day on weekends. BNSF Railway (BNSF) operates 4 to 6 freight rail service seven days per week[24]. These train operations on a single track are within estimated average capacities of the freight corridor.

The current travel time by Amtrak Pacific Surfliner which operates between the two endpoint stations - San Clemente Pier and Oceanside Transportation Center - is 23 minutes and covers a distance of 21 miles. This shows that the train operates at an approximate speed of 60 miles per hour between the two stations. As per NCHRP Report 773, the current line supports 48 trains per day for the single track configuration. This corresponds to almost 30 minutes of headway.

The quantified results presented in this report are short-term outputs – immediately after the new double track line becomes operational for freight and passenger trains.

[23] NCHRP Report 773 (2014) - Capacity Modeling Guidebook for Shared-Use Passenger and Freight Rail Operations.
[24] CP San Onofre to CP Pulgas Double Track Project Phase 2, Project Study Report, http://www.dot.ca.gov/hq/transprog/ocip/final_2018_itip/75-SD%20CP%20San%20Onofre%20to%20CP%20Pulgas.pdf

Based on the 2017 GIS data from Caltrans[25], the annual average daily traffic (AADT) for passenger cars on along the track for route I-5 is around 133,589. The truck AADT on the I-5 is 10,411.

Figure D1: Project location details - San Onofre to Pulgas Double Track Phase 2

[25] Caltrans GIS Data, Truck Traffic Volumes (Truck AADT), accessed on March 22, 2019. http://www.dot.ca.gov/hq/tsip/gis/datalibrary/Metadata/TruckAADT.html

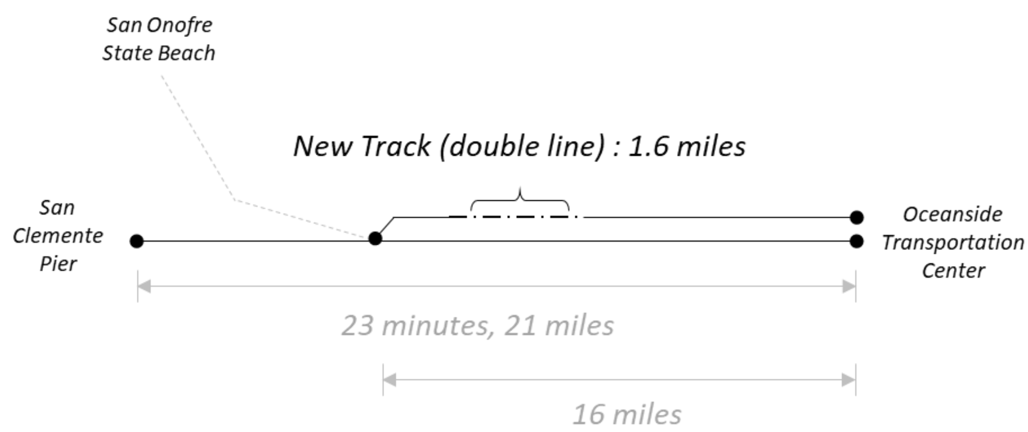

Figure D2: Double track configuration project details

Accessibility Measure

As per the NCHRP Report 773, with double track line completion in 2020–2025, there is a potential of headway to be reduced to 10 minutes from the current 30 minutes. This will increase the capacity of the line to 150 trains per day with the double track configuration. Since accessibility is inversely proportional to impedance (travel time)[26], the station-level accessibility (in percentage change) is calculated as: $\left(\frac{\frac{1}{10}-\frac{1}{30}}{\frac{1}{30}}\right) \times 100 = \mathbf{200}\%$ **.** This is for the stations at the two endpoints of the rail line – San Clemente Pier and Oceanside Transportation Center.

Ridership

Based on the information gathered from the NCHRP Report 773, the capacity of double track on this rail route in 2020-2025 will increase by 6 trains per day. As per the recent Federal Railroad Association (FRA), quarterly performance report, each Pacific Surfliner train carries 158 passengers (FRA, 2019[27]). Total riders based on 38 passenger trains per day on weekdays is 38×158 = 6,004 riders. Therefore, a potential of increase in 6×158 = 948 riders per day will be added in short-term to passenger rail after the completion of double track line on this rail route.

[26] Chandra, S. and Vadali, S., 2014. Evaluating accessibility impacts of the proposed America 2050 high-speed rail corridor for the Appalachian Region. Journal of Transport Geography, 37, pp.28-46.
[27] Quarterly Report on the Performance and Service Quality of Intercity Passenger Train Operations, Federal Railroad Administration, February 2019.

Greenhouse Gas (GHG) Emissions (and other criteria pollutants) Measure

Passenger rail emission reductions

The emission rates for passenger cars are calculated based on rates obtained from the United States Environmental Protection Agency (EPA). The rates are provided in Table D1. Emissions are calculated for weekday operations of the passenger trains. Based on the assumption (as before) that 6 trains per day that are added to the double track line are all passenger trains, for each train with 158 passengers. Thus, a total of 6×158 = 948 daily passenger cars which otherwise would have used the I-5 freeway adjacent to the San Onofre to Pulgas double track. Total riders under current operations with 38 trains per day on a weekday are 38×158 = 6,004 daily passenger cars.

For the1.6-mile equivalent length of the new double track line:

Total emissions from 133,589 passenger vehicles for SINGLE track line is (1.034+9.400+0.693+368.4) ×1.6×133,589 = 81121012 grams = 81.1 metric tons.

Total emissions from 133,589 passenger vehicles for DOUBLE track line is (1.034+9.400+0.693+368.4) ×1.6×(133,589 – 948) = 80545345 grams = 80.5 metric tons.

Freight rail emission reductions

A freight train can be considered as equivalent to 140 freight trucks. For daily operations on the new line, minimum GHG emissions would result from 2 more additional freight trains that would become operational on a daily basis by BNSF – since it currently operates 4 to 6 trains daily. Total emission reductions from the regular 6 freight train operations would be equivalent to emissions reductions from 2×140 = 280 trucks, over 1.6 miles of equivalent freeway use.

Total emissions from 10,411 trucks for SINGLE track line is (1.224+11.84+0.95+513.5) ×1.6×10, 411 = 8787117 grams = 8.8 metric tons.

Total emissions from 10,411 trucks for DOUBLE track line is (1.224+11.84+0.95+513.5) ×1.6×(10, 411-280) = 8550791 grams = 8.6 metric tons.

Table D1: Input emission rates by type of vehicle, grams per mile[28]

Vehicle Type	VOC	CO	NOx	CO_2
Passenger Cars	1.034	9.400	0.693	368.4
Trucks*	1.224	11.84	0.95	513.5

* assuming light-duty trucks

[28] Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks, United States Environmental Protection Agency (EPA), Office of Transportation and Air Quality, October 2008. Accessed on May 22, 2019. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100EVXP.TXT. , U.S. Department of Transportation, 2019.

Resource Utilization (Energy Savings) Measure

Energy savings are determined based on the 2014 energy intensity values of transportation modes for highways (trucks) and railroad (freight rail). Energy intensity is defined as the amount of energy used to produce a given level of output or activity which is measured by vehicle-miles, freight-car-miles, or ton-miles. Energy intensity value for highways (heavy single-unit and combination freight trucks) is 21,573 BTU[29] per vehicle-mile and 14,533 BTU for the railroad per freight-car-mile (these data are available from the Oak Ridge National Laboratory[30] report published in 2016).

Freight rail energy savings

There is potential for energy consumption with an increase in rail frequency on the double line track. This is due to decrease in truck volumes on adjacent I-5. If one rail car can carry one TEU (twenty-foot equivalent unit) container along the new double line rail route, it could replace 140 (7000/50= 140, see footnote for further note[31]) heavy single-unit trucks from the freeway (with an assumption that the train has 140 rail cars). This can occur with two more additional trains which BNSF can operate daily (in addition to 4 daily trains). This could replace equivalent of 2×140 trucks from the freeway daily, with total energy savings of 2×21,573×140 ×1.6 - 2×14,533×140×1.6 = ***3.1 million BTU*** for the 1.6 mile stretch of new double track line.

[29] BTU stands for British Thermal Unit as measurement for energy

[30] Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 35 (Oak Ridge, TN: annual issues), table 2.17, published in 2016 and available at http://cta.ornl.gov/data/index.shtml

[31] Assumed length of freight train is approximately 7000 feet with each car length being 50 feet in length for 1.6 miles of total double line travel.

Quantification of Outputs

Table D2: Formulation for quantifying accessibility measure

Measure	*Metric*	*Definition*	*Output Expression*	*% Increase*
Accessibility	Increase in stop-level accessibility along the route	$StopAccess_{before}$ = population or jobs accessible around stops before the improvement/investment = (1/30) $StopAccess_{after}$= population or jobs accessible around stops after the improvement/investment = (1/10)	$Output\ 1 = \left(\frac{StopAccess_{after} - StopAccess_{before}}{StopAccess_{before}}\right) \times 100$	200%
	Ridership and boarding counts along the route (before and after the project)	$ridership_{before}$ = ridership or boarding along the route before the improvement/investment **= 6,004 passengers per day** $ridership_{after}$= ridership or boarding along the route after the improvement/investment **= 6,952 passengers per day**	$Output\ 1 = \left(\frac{ridership_{after} - ridership_{before}}{ridership_{before}}\right) \times 100$	15.8%

Table D3: Formulation for quantifying greenhouse gas emissions measure

Measure	*Metric*	*Definition*	*Output Expression*	*% Reduction*
Greenhouse Gas (GHG) Emissions (and other criteria pollutants)	GHG emissions for cars and diesel fleets	$GHGemissions_{before}$ = total greenhouse gas emissions reductions (including criteria pollutants) before the improvement/investment = 81.1 + 8.8 **= 89.9 metric tons** $GHGemissions_{after}$ = total greenhouse gas emissions reductions (including criteria pollutants) after the improvement/investment = 80.5 + 8.6 **= 89.1 metric tons**	$Output\ 1 = \left(\frac{GHGemissions_{after} - GHGemissions_{before}}{GHGemissions_{before}}\right) \times 100$	0.9%

Table D4: Formulation for quantifying mobility measure

Measure	*Metric*	*Definition*	*Quantified Output*	*% Increase*
Mobility	Number of passenger (or freight) trips for a project (route and service)	$PassFreightTrips_{before}$ = ridership before the improvement/investment **= 6,004 passenger per day** $PassFreightTrips_{after}$ = ridership after the improvement/investment **= 6,952 passenger per day**	$Output\ 1 = \left(\frac{PassFreightTrips_{after} - PassFreightTrips_{before}}{PassFreightTrips_{before}}\right) \times 100$	15.8%
	Number of transit service hours	$TransitSerHrs_{before}$ = number of transit service hours before the improvement/investment **=38** $TransitSerHrs_{after}$ = number of transit service hours after the improvement/investment **=44**	$Output\ 1 = \left(\frac{TransitSerHrs_{after} - TransitSerHrs_{before}}{TransitSerHrs_{before}}\right) \times 100$	15.8%

Table D5: Formulation for quantifying travel time measure

Measure	*Metrics*	*Definition*	*Output Expression*	*% Reduction*
Travel Time	Scheduled travel time *Note: Total travel time between the two stations - San Clemente Pier and Oceanside Transportation Center - using 22-mile distance on I-5 is 35 min under congested scenarios (Source: Google Maps, 2019). This is equivalent to 2.5 minutes over 1.6-mile distance under the same congested scenario on I-5.* *1.6-mile distance on double track line is 1.6 minutes with 60 miles per hour speed of the passenger rail. Net decrease in travel time using passenger rail between San Clemente Pier and Oceanside Transportation Center stations is 2.5 – 1.6 = 0.9 minutes*	$SchedEqui_{before}$ = scheduled travel time before the improvement/investment **= 2.5 minutes** $SchedEqui_{after}$ = scheduled travel time after the improvement/investment **= 1.6 minutes**	$Output\ 1 = \left(\frac{SchedEqui_{before} - SchedEqui_{after}}{SchedEqui_{before}}\right) \times 100$	36 %

Table D6: Formulation for quantifying resource utilization measure

Measure	*Metric*	*Definition*	*Output Expression*	*% Savings*
Resource Utilization	Vehicle miles per kilowatt-hour of power consumed (energy savings)	$VehMikW_{before}$ = vehicle miles per kilowatt-hour of power consumed before the improvement/investment **= 9.6 million BTU** $VehMikW_{after}$ = vehicle miles per kilowatt-hour of power consumed after the improvement/investment **= 6.5 million BTU**	$Output\ 1 = \left(\frac{VehMikW_{before} - VehMikW_{after}}{VehMikW_{before}}\right) \times 100$	32.2%

PROJECT E - SHAFTER SATURDAY DAR SERVICE

Project Overview

The City of Shafter is located in California's Kern County - which is primarily rural. The Dial-A-Ride service in Shafter serves the city as well as the Census Designated Place (CDP) communities of Mexican Colony and Smith Corner to the south, and the local Shafter-Minter Field airport to the east ([32]). See Figs. E1, E2, and E3. The Dial-A-Ride service is offered during regular weekday service hours from 7:30 a.m. to 4:30 p.m., Monday through Friday, using two vehicles. A Saturday service with one vehicle is offered between 10:30 a.m. to 3:30 p.m. The total funding provided for the project is $21,918. The project had a start date of July 1, 2016, and an end date of September 29, 2017. The purpose of the project was to provide greenhouse gas (GHG) emission reductions (Source: LCTOP Annual Report, 2018). Based on a brief telephone interview with Shafter Dial-a-Ride representative, each bus has a capacity of nine passengers. One-way adult fare is $1.00 with an additional charge of $0.25 for trips outside the city limits. Both Mexican Colony and Smith Corner are outside the city limits.

Table E1 shows emission rates for passenger car and transit bus modes with corresponding emission calculations compiled in Table E2.

Figure E1: Smith Corner (approximately 2 miles from Shafter Dial-a-Ride terminal, Google Maps)

[32] Shafter Transit System Dial-A-Ride Title VI Program, accessed on March 30, 2019. https://www.shafter.com/148/Transit and https://www.shafter.com/DocumentCenter/View/4144/Shafter-2017-Title-VI-Update_final?bidId=

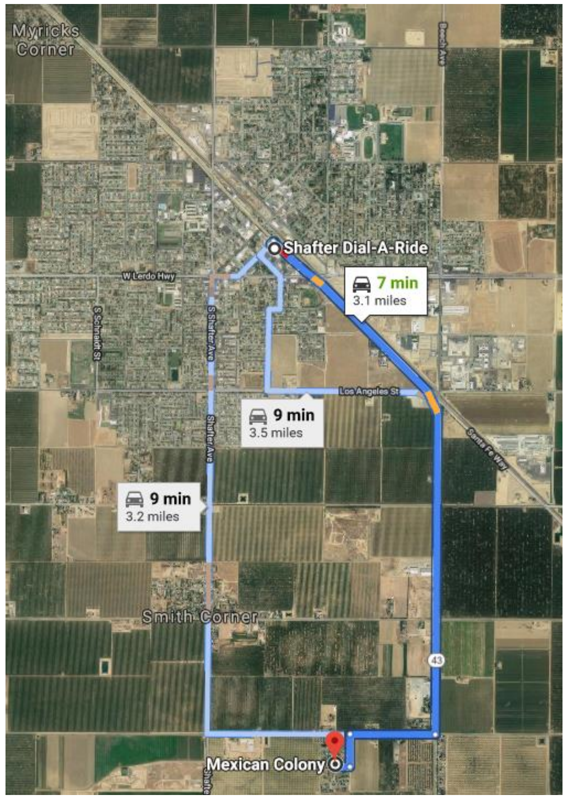

Figure E2: Mexican Colony (approximately 3 miles from Shafter Dial-a-Ride terminal, Google Maps)

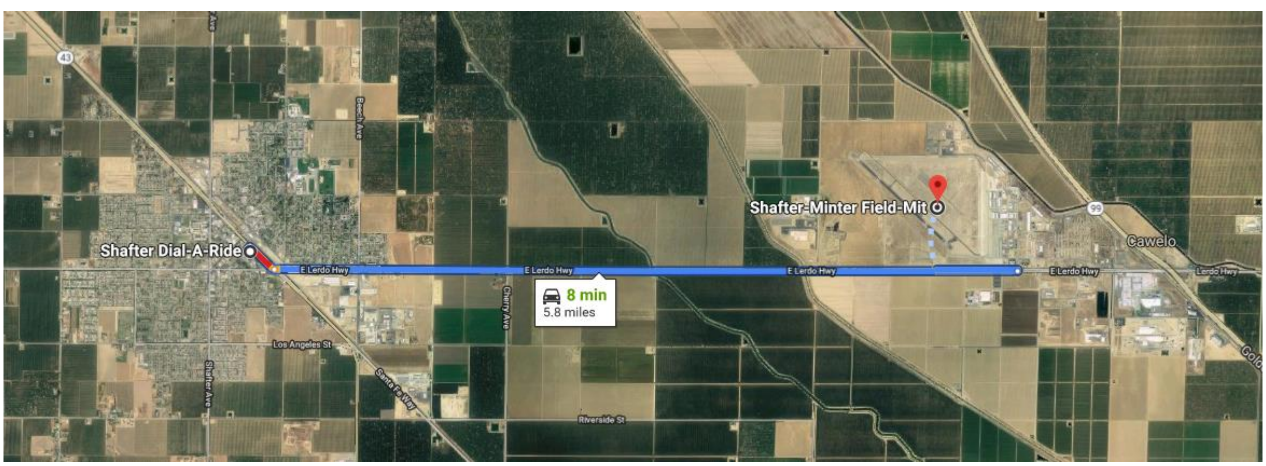

Figure E3: Shafter-Minter Field airport (approximately 5.8 miles from Shafter Dial-a-Ride terminal, Google Maps)

Table E1: Input emission rates by type of vehicle, grams per mile[33]

Vehicle Type	CO	NOx	CO_2
Passenger Cars	9.400	0.693	368.4
Buses	7	25	3100

.

[33] Lambert, C.D., Vojtisek-Lom, M. and Joshua Wilson, P., 2002. Evaluation of on road emissions from transit buses during revenue service. In 11th Annual Emission Inventory Conference, Atlanta.

Table E2: Emissions comparisons

Destination Location	Shortest Travel Distance from Dial-A-Ride Terminal (in miles)	Emissions per Passenger (using Dial-A-Ride bus service) in grams			Equivalent Passenger Car Travel Distance from Dial-A-Ride Terminal (in miles)	Emissions per Passenger (using a passenger car) in grams		
		CO	NOx	CO_2		CO	NOx	CO_2
Smith Corner	1.8	**1.4** =1.8×7/9	**5** =1.8×25/9	**620** =1.8×3100/9	1.8	**16.92** =1.8×9.4	**1.25** =1.8×0.693	**663** =1.8×368.4
Mexican Colony	3.2	**2.48** =3.2×7/9	**8.89** =3.2×25/9	**1102** =3.2×3100/9	3.2	**30.08** =3.2×9.4	**2.22** =3.2×0.693	**1179** =3.2×368.4
Shafter-Minter Field Airport	5.8	**4.51** =5.8×7/9	**16.11** =5.8×25/9	**1998** =5.8×3100/9	5.8	**54.52** =5.8×9.4	**4.02** =5.8×0.693	**2137** =5.8×368.4

Therefore, based on the compiled information on emissions in Table E2, the following conclusions can be made:

i) Total emissions with passenger car use to all three destination locations per trip per passenger = 4,088 grams
ii) Total emissions with Saturday Dial-A-Ride service to all three destination locations per trip per passenger = 3,758 grams

Quantification of Outputs

Table E3: Formulation for quantifying greenhouse gas emissions measure

Measure	Metric	Definition	Output Expression	% Reduction with Saturday Service
Greenhouse Gas (GHG) Emissions (and other criteria pollutants)	GHG emissions for cars and diesel fleets	$GHGemissions_{bef}$ = total greenhouse gas emissions reductions (including criteria pollutants) before the improvement/investment **= 4088 grams per trip per passenger for Saturday** $GHGemissions_{aft}$ = total greenhouse gas emissions reductions (including criteria pollutants) after the improvement/investment **= 3758 grams per trip per**	$Output\ 1 = \left(\frac{GHGemissions_{before} - GHGemissions_{after}}{GHGemissions_{before}}\right) \times 100$	8%

		passenger for Saturday		

Table E4: Formulation for quantifying mobility measure

Measure	*Metric*	*Definition*	*Output Expression*	*% Increase with Saturday Service*
Mobility	Number of transit service hours	$TransitSerHrs_{before}$ = number of transit service hours before the improvement/investment **= 10×5 hours = 50 hours** $TransitSerHrs_{after}$ = number of transit service hours after the improvement/investment **= 10×5 + 5 hours = 55 hours**	$Output\ 1 = \left(\frac{TransitSerHrs_{after} - TransitSerHrs_{before}}{TransitSerHrs_{before}}\right) \times 100$	10%
	Frequency of service on route	$FreqService_{before}$ = frequency of service on route before the improvement/investment **= 5 days a week**	$Output\ 1 = \left(\frac{FreqService_{after} - FreqService_{before}}{FreqService_{before}}\right) \times 100$	20%

		$FreqService_{after}$ = frequency of service on the route after the improvement/investment **=6 days a week (including Saturday)**		

PROJECT F - CLIPPER FARE PAYMENT SYSTEM

Project Overview

The Clipper Fare Payment System project started on April 1, 2016 and has a total project investment of \$ 6,559,290. The payment system replaces universal fare card equipment and devices on transit operator vehicles, including buses and rail vehicles. Equipment includes network equipment, hardware, software and peripherals that have reached the end of its useful service life.

The analysis is carried out for the two largest rail transit systems by ridership. These are Bay Area Rapid Transit (BART) and Caltrain. Clipper is the all-in-one transit card for the Bay Area ([34]) and is used on all major Bay Area transit systems including BART and Caltrain. Discounts are offered on Clipper card - 50 cents for adults. The Metropolitan Transportation Commission (MTC), as a public agency, is responsible for Clipper. The map in Fig. F1 shows the two closest stops,16th St Mission and 24th St Mission, for BART. The fare between these two stops without discount is \$2.50[35]; therefore, with Clipper card percentage discount for an adult fare is 0.50×100/2.50 = 20% for BART. This percentage discount becomes smaller with longer trips made with BART.

Adult Clipper cards for Caltrain cost \$3.20 per trip for one zone[36]. The minimum cost of adult full fare without the card is \$ 3.75 per trip per zone. The percentage discount with Clipper card is 0.55×100/3.20 = 17% for adults for Caltrain.

[34] Clipper, accessed on March 31, 2019. https://www.clippercard.com/ClipperWeb/whatsTranslink.do

[35] Fare Calculator, BART, accessed on March 31, 2019. https://www.bart.gov/tickets/calculator

[36] Fare Chart, Caltrain, accessed on March 31,2019. http://www.caltrain.com/Fares/farechart.html?

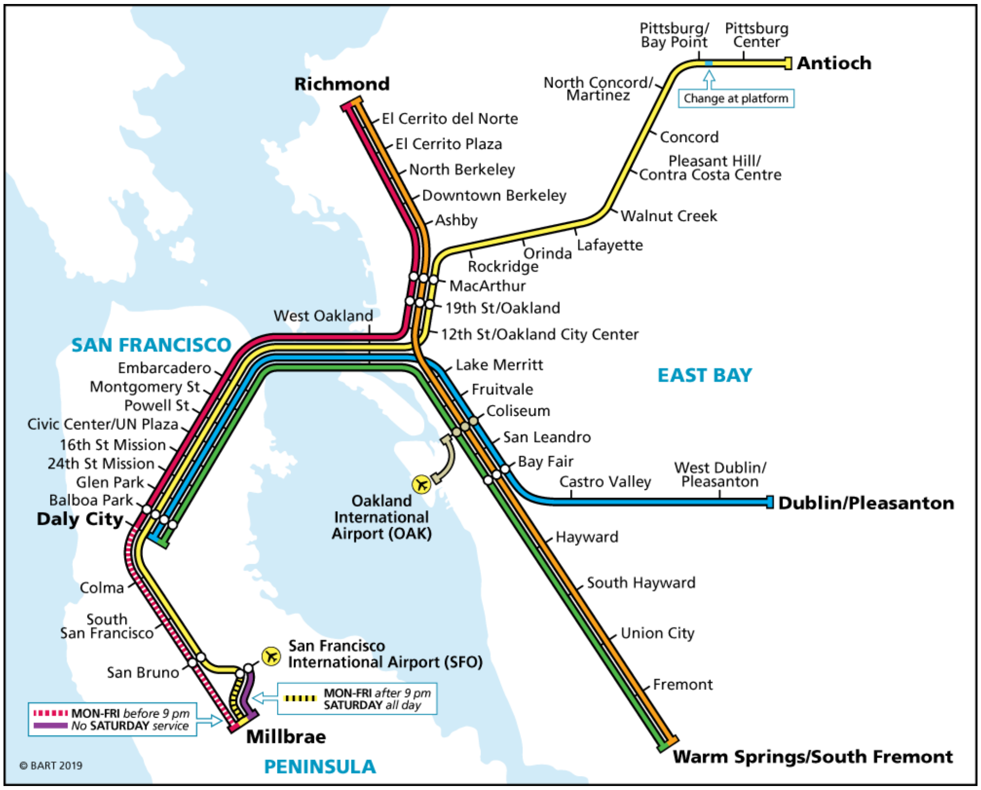

Figure F1: Weekday & Saturday Service Map (Source: BART, 2019)[37]

Additional analysis consisted of examining any ridership changes (from the end of March 2016 to the end of April 2016) for BART due to Clipper Fare Payment System replacement. For Caltrain, available data from past customer surveys were used to assess the percentage increase in the usage of Clipper Caltrain Monthly Pass from 2016 to 2018.

The monthly ridership for BART is compiled in Table F1. The percentage change in Clipper Pass use is provided under Table F2 for the weekday and weekend transit users for the data available for Caltrain.

Based on Table F1, the percentage change in ridership after Clipper Fare Payment System implementation is (434,735 - 431,535) ×100/431,535 = 0.7%.

With Caltrain, the percentage change in ridership is based on percentage usage of Clipper Pass in Table F2, which is (39.3 + 12.5 – 39.1 – 6.1) ×100/ (39.1 + 6.1) = 14.6%. Therefore, the total reduction in emissions just from the two transit systems of BART and Caltrain is 14.6 + 0.7 = 15.3%.

[37] Bay Area Rapid Transit (BART), accessed on April 12, 2019. https://www.bart.gov/tickets/calculator

Table F1: Ridership compilation

Transit Agency	Average Weekday Ridership	
	March 2016	April 2016
BART	431,535	434,735

Table F2: Customer usage of Clipper Pass for analysis years

Transit Agency	% Using Clipper Caltrain Monthly Pass			
	Year 2016[38]		Year 2018[39]	
	Weekday	Weekend	Weekday	Weekend
Caltrain	Total Respondents = 5051, Monthly Clipper Caltrain Users = 1975	Total Respondents = 445, Monthly Clipper Caltrain Users = 27	Total Respondents = 2905, Monthly Clipper Caltrain Users = 1141	Total Respondents = 377, Monthly Clipper Caltrain Users = 47
Percentage usage of Clipper Pass	**39.1**	**6.1**	**39.3**	**12.5**

[38] Caltrain Triennial Customer Survey 2016, accessed on March 31, 2019. http://www.caltrain.com/Assets/_MarketDevelopment/pdf/Caltrain+2016+Triennial+Tables.pdf

[39] Caltrain Customer Satisfaction Survey 2018, accessed on March 31, 2019. http://www.caltrain.com/Assets/_MarketDevelopment/pdf/2018+Customer+Satisfaction+Survey+Tables.pdf

Quantification of Outputs

Table F3: Formulation for quantifying cost measure

Measure	*Metric*	*Definition*	*Output Expression*	*% Reduction*
Costs	Cost per trip (or PMT, VMT)	$CoPMT_{before}$ = cost per passenger-miles traveled before the improvement/investment **= $2.50 (for BART)** $CoPMT_{after}$ = cost per passenger-miles traveled after the improvement/investment **= $2.00 (for BART)**	$Output = \left(\frac{CoPMT_{before} - CoPMT_{after}}{CoPMT_{before}}\right) \times 100$	20%

Table F4: Formulation for quantifying mobility measure

Measure	*Metric*	*Definition*	*Output Expression*	*% Increase*
Mobility	Ridership and boardings	$Ridership_{before}$ = ridership before the improvement/investment **= 431,535 (for BART)** $Ridership_{after}$ = ridership after the improvement/investment **= 434,735 (for BART)**	$Output = \left(\frac{Ridership_{after} - Ridership_{before}}{Ridership_{before}}\right) \times 100$	0.7%

PROJECT G - PURCHASE 29 -45' BUSES

Project Overview

The project provided local match funding for 25-45' diesel over-the-road replacement coaches for the Golden Gate Bridge Highway and Transportation District in Marin county. The project replaced those coaches that had reached the end of their useful life. The coaches replaced were model year 1996. Each new coach has 57 passenger seats with two wheelchair positions. The total project cost was $16,797,854. The project begin date was in April 2014, and the end close-out phase was in September 2016. The entire fleet of buses is also bike rack-equipped[40]. As per the Golden Bridge Report of August 2017, emission reductions were reported to be more than 14%[41].

Table G1 outlines typical vehicle operating and maintenance cost with age for diesel operated buses. The information is utilized to compute potential percentage change in transit bus operating and maintenance costs.

Table G1: Operating and maintenance cost with age for a diesel bus (Source: CalEPA, 2016)[42]

	Vehicle Age (in years)			
	1	**10**	**15**	**20**
Operating and Maintenance Cost (in $ per mile)	$1.7	$2.2	$2.4	$2.6

Operating and maintenance cost per mile for 25 diesel buses after 20 years of service: 25×2.6 = $65 per mile

Operating and maintenance cost per mile for 25 diesel buses within a year of service: 25×1.7 = $42.5 per mile

With an assumption that the new 25 diesel buses replaced 25 old diesel buses, the operating and maintenance cost reduction per mile is $22.5.

[40] The GGT Fleet - Updated April 2015, accessed on March 21, 2019. http://goldengatetransit.org/researchlibrary/fleet.php

[41] Final Project Report, Golden Gate Bridge, Highway & Transportation District, accessed on March 20, 2019. https://bondaccountability.dot.ca.gov/CloseoutDocumentViewPreAction.do?reportTypeNbr=1&cmiaproj=10/11-4-2H(010)

[42] Advanced Clean Transit Program, California Environmental Protection Agency, Air Resources Board, August 2016.

Quantification of Outputs

Table G2: Formulation for quantifying cost measure

Measure	*Metric*	*Definition*	*Output Expression*	*% Reduction*
Costs	Operating cost per passenger -mile	$OperCostPass_{before}$ = operating cost per passenger mile before the improvement/investment **= $65** $OperCostPass_{after}$ = operating cost per passenger mile after the improvement/investment **= $42.5**	$Output\ 1 = \left(\frac{OperCostPass_{before} - OperCostPass_{after}}{OperCostPass_{before}}\right) \times 100$	34.6%

Table G3: Formulation for quantifying greenhouse gas emissions measure

Measure	*Metric*	*Definition*	*Output Expression*	*% Reduction*
Greenhouse Gas (GHG) Emissions (and other criteria pollutants)	GHG emissions for cars and diesel fleets	$GHGemissions_{before}$ = total greenhouse gas emissions reductions (including criteria pollutants) before the improvement/invest ment	$Output\ 1 = \left(\frac{GHGemissions_{after} - GHGemissions_{before}}{GHGemissions_{before}}\right) \times 100$	14%

		$GHGemissions_{after}$ = total greenhouse gas emissions reductions (including criteria pollutants) after the improvement/investment		

DISCUSSION AND CONCLUDING REMARKS

A decision matrix was developed based on the findings of various outcomes of the quantified measures. The matrix is presented in Table 2 and it shows the impact of investment in dollars on measures. Note that due to unavailability of information of project-specific details, the quantification has been carried out for short-term impacts only. Assessment for long term impacts will involve in-depth data collection through interviews with stakeholders for all the seven projects reviewed in this research. The findings from the matrix in Table 2 have also been illustrated using charts shown in Figs. 1 – 6.

The matrix presented in Table 2 shows that the data availability for Project D - San Onofre to Pulgas Double Track Phase 2 was enough to quantify 50% of the measures – accessibility, costs, GHG emissions, mobility, travel time and resource utilization. For other projects, at most two measures could be quantified.

When compared across the projects, Project B- Redlands Passenger Rail experienced very high accessibility and mobility increase. This is expected as a completely new passenger rail line will become operational with the project connecting key five stations in San Bernardino County.

Table 2: Decision matrix for assessing impact of transit investments

	Investment	Accessibility Increase	Cost Reductions	GHG Emissions Reductions	Mobility Increase	Travel Time Reductions	Resource Utilization Increase
Project A	$ 1,305,009		8.00%	22.37%			
Project B	$ 282,277,000	252.94%			159.05%		
Project C	$ 79,192,000			32.72%		32.72%	
Project D	$ 30,040,000	106.18%		0.88%	15.79%	36.00%	32.29%
Project E	$ 21,918			48.41%	15.00%		
Project F	$ 6,559,290		20.00%		0.74%		
Project G	$16,797,854		34.62%	14.00%			

Project A - Purchase Replacement Transit Vehicles
Project B - Redlands Passenger Rail
Project C - Rt 34 Fifth St - Rice Avenue Grade Separation
Project D - San Onofre to Pulgas Double Track Phase 2
Project E - Shafter Saturday DAR Service
Project F - Clipper Fare Payment System
Project G - Purchase 29 -45' Buses

For the accessibility measure, Project D - San Onofre to Pulgas Double Track Phase 2 recorded the second highest percentage increase. For cost measure, Project G - Purchase 29 - 45' Buses had the highest reduction while Project A - Purchase Replacement Transit Vehicles had the least percentage decrease. Project E - Shafter Saturday DAR Service had the highest percentage GHG emission reduction while Project D - San Onofre to Pulgas Double Track Phase 2 had the lowest percentage reduction. For the mobility impacts, Project F - Clipper Fare Payment System had the lowest quantified increase, whereas Project B - Redlands Passenger Rail had the largest percentage mobility increase. Project C - Rt 34 Fifth St - Rice Avenue Grade Separation and Project D - San Onofre to Pulgas Double Track Phase 2 had almost similar percentage decrease in travel time. Project D - San Onofre to Pulgas Double Track Phase 2 had an increase in the percentage of resource utilization.

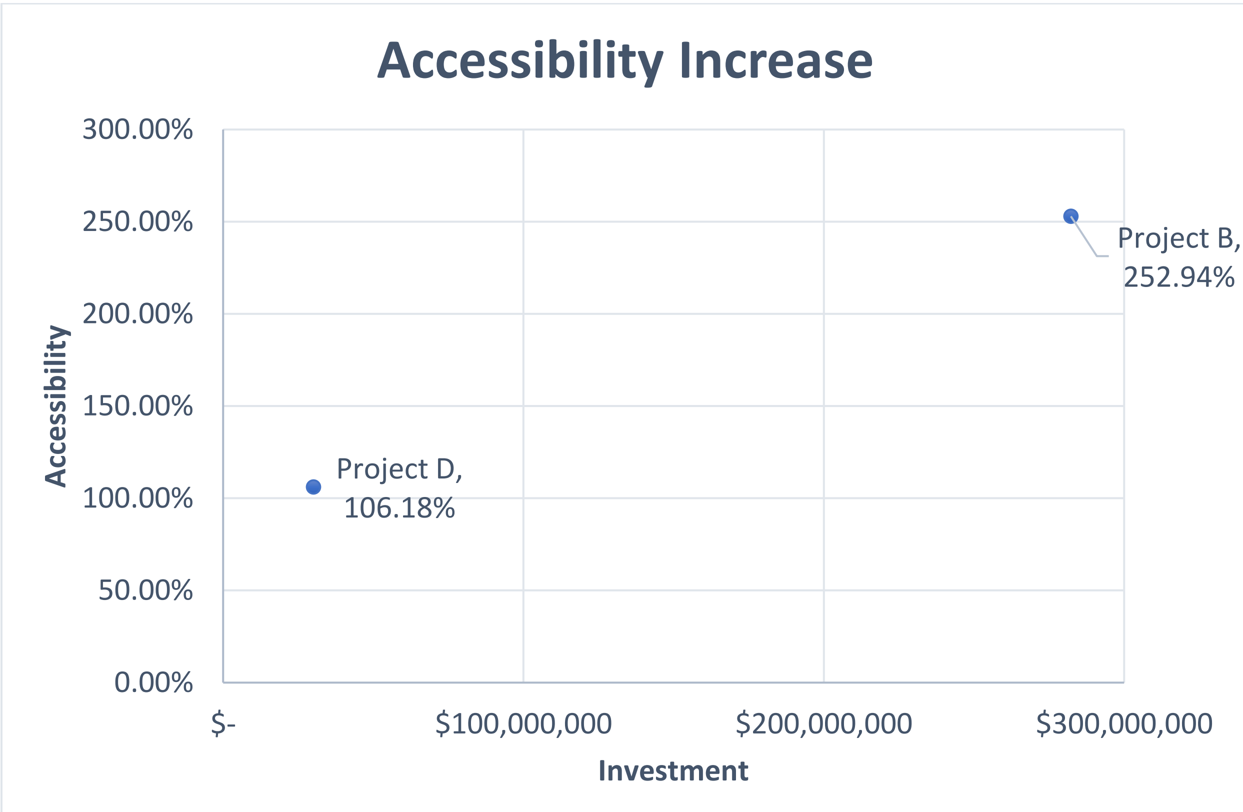

Figure 1: Percentage accessibility increase with investment

Figure 2: Percentage cost decrease with investment

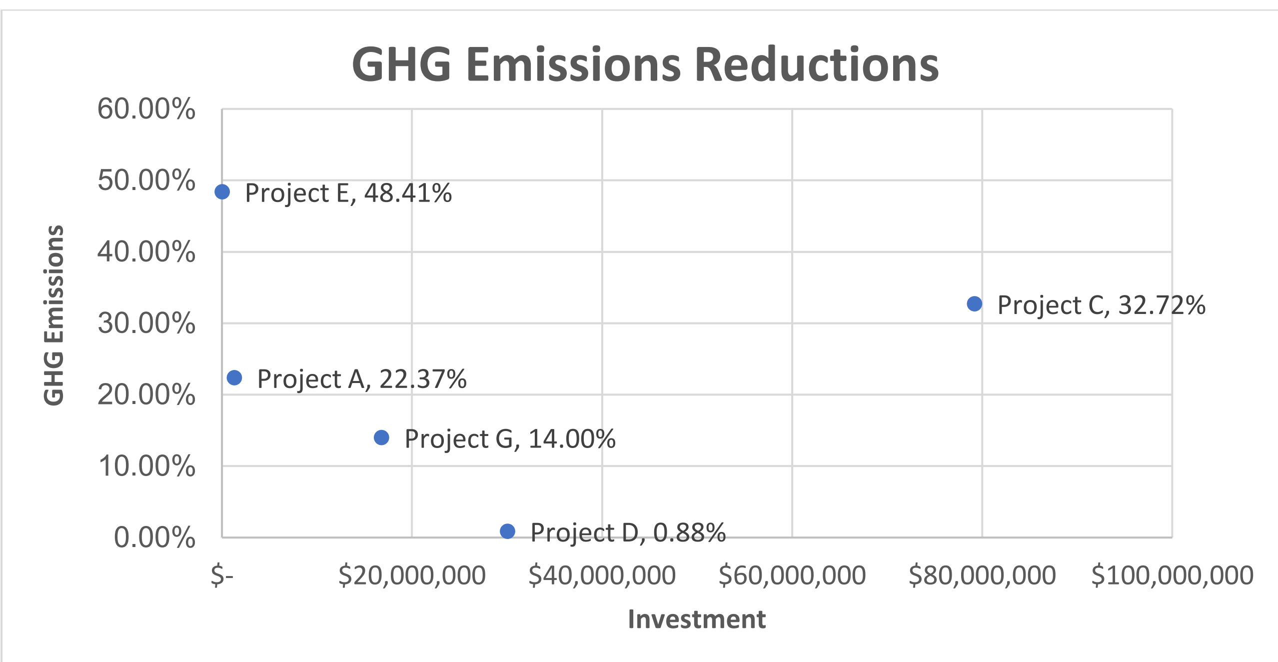

Figure 3: Percentage of GHG emission decrease with investment

Figure 4: Percentage mobility increase with investment

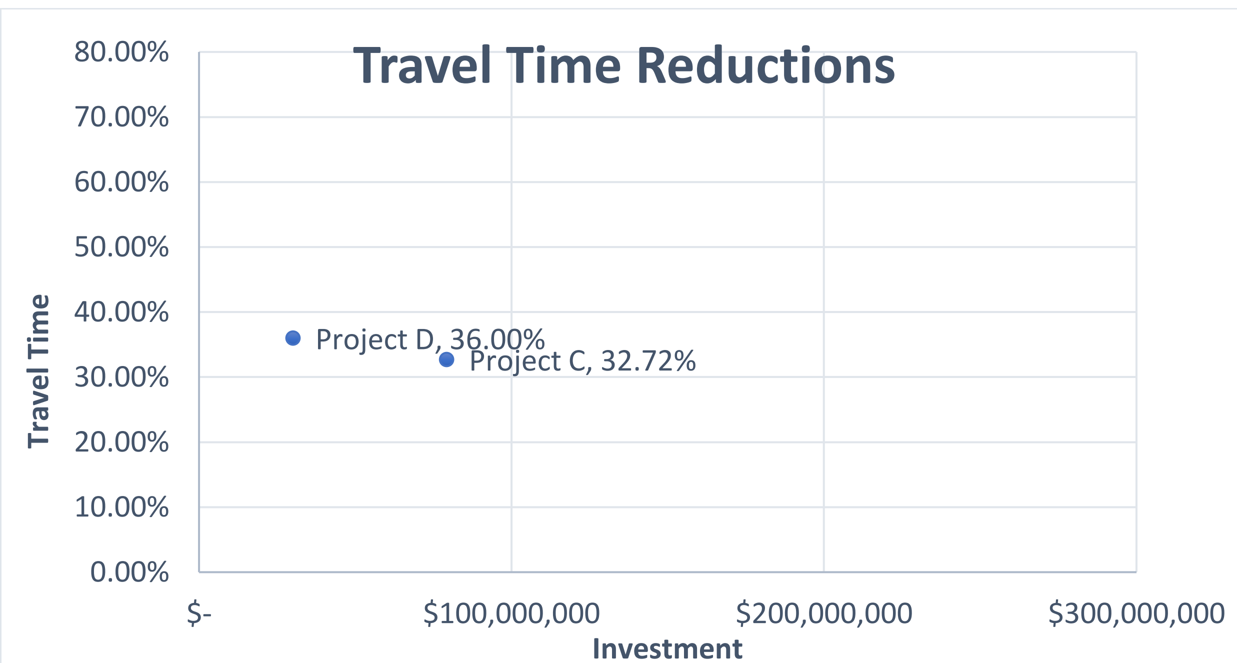

Figure 5: Percentage of travel time decrease with investment

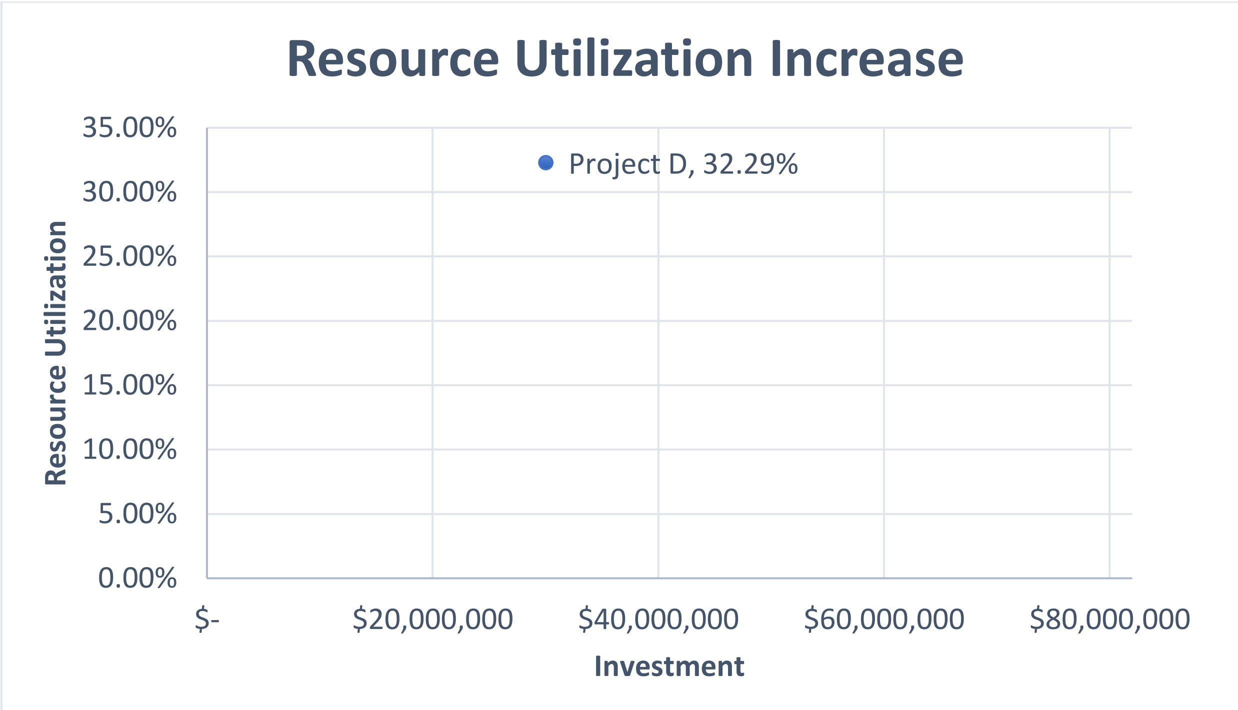

Figure 6: Percentage decrease in resource utilization with investment

The data collection for analysis were carried out based on information gathered from available reports and online web searches. No information could be obtained on land use, safety and security, service quality and economic development data for any project through online web searches. Thus, these measures could not be reported for any project reviewed as part of this research.

Recommendations

Based on the projects reviewed in this research, it is recommended that Caltrans should consider measuring outcomes that can be directly quantified – defined as 'active' measures. Measures that cannot be directly quantified or estimated can be categorized as 'passive' measures. Measures that can be classified as 'active' measures consist of those that are at the immediate geographical vicinity of the influence of the project. 'Passive' measures are those that have no fixed geographical boundaries to be defined for their measurement but are very important. A project can have both active and passive measures. For example, an active measure for Redlands Passenger Rail project reviewed in this research is 'travel time' reduction and it is estimated to be 17 minutes with the new 9-mile rail line and average speed of the new rail service. A passive measure for the project would be GHG emissions reductions. While travel time was directly estimated between the two endpoints of the route of the passenger line, measures such as GHG emissions need to be calculated considering mode shifts of passengers due to the new rail line service.

In addition, both short-term and long-term benefits accruing from a project should be tracked. A short-term assessment of measures could be after a day, a week, a month, a year or a few years when the project is completed and operational. A long-term assessment of measures is usually more than ten years or as per the policies laid out in the planning process of the stakeholders. Both short-term and long-term assessments are heavily dependent on the magnitude and spatial extent of investment. A long-term project will usually yield a higher magnitude of the measured outcomes as compared to a short-term project.

It is expected that for a project with a very high value of investment spanning several years and spread on a larger spatial scale, long-term assessment is more suitable – such as the REDLANDS PASSENGER RAIL project reviewed in this research. This project has a total investment of $282 million from 2019 through 2024 but once completed the benefits will accrue for a longer period. A short-term assessment is more suitable for the additional dial-a-ride service provided under the SHAFTER SATURDAY DAR SERVICE project. In this project, an immediate shift of 9 passengers per trip from car to transit on Saturday can potentially seem to occur.

Table 3 provides a matrix of issues (pros and cons) that Caltrans should consider in tracking project benefits in its goals and planning policies.

Table 3: Key considerations for quantifying project outcomes

	Type of Quantifiable Measures	
Time Period of Assessment	**Active**	**Passive**
Short Term	**Pros**: Benefits under this category are usually easy to quantify. **Cons**: Benefits can vanish in the long-term assessment since other projects in the vicinity interfere with the benefits.	**Pros**: Benefits under this category are impactful if properly assessed and can trigger a large-scale benefit in the long run. Example – introduction of a new service fleet could encourage more ridership, and a steady rise in ridership can be observed every year. **Cons**: Benefits under this category are difficult to quantify (such as capturing precise GHG emissions or employment creations due to a new service fleet)
Long Term	**Pros**: Benefits under this category are easily quantifiable and can be quantified systematically at fixed or	**Pros**: Benefits under this category if quantified properly can be very useful and can allow for customized assessment of type and form of

	regular time periods. In most of the projects under this category, travel time savings is often the assessed measure and it triggers other added benefits. Another example is the real estate value increase around the project location which can be systematically tracked every year. **Cons**: Often benefits under this category are inversely correlated to other benefits such as decrease in travel time resulting in increase in traffic in the long run and causing high GHG emissions.	benefits systematically at fixed or regular time periods. Benefits under this category often trigger large scale development spanning several industry sectors. Example - with a new rail line there is expected creation of new jobs not directly attributed due to the new rail line. **Cons**: Often benefits under this category are difficult to assess and could be misleading if not assessed scientifically with accurate simulation methods. Several parameters need to be determined and assessed to estimate the benefits. Further, interference in estimating results from other projects (such as policy changes, taxes etc.) not related to transportation are unavoidable.

APPENDIX

Formulations and Methodology

Introduction: This section provides the formulations for a comprehensive list of metrics that are used to calculate performance measures for the spreadsheet-based tool. Note that most of these metrics require data to be known beforehand and the values are required as input for the tool. The outcome of the tool is to show how performance measures vary with project investment. At present, the tool is capable to show this variation for the seven projects reviewed in this research.

Table I: Formulation for quantifying accessibility measure

Measure	*Metric*	*Definition*	*Quantified Output*
Accessibility	Meeting requirements of the Americans with Disabilities Act (ADA) such as compliance and coverage of transit services (for example, distance between stops and proximity to disadvantaged communities)	D_{before} = distance between stops before the improvement/investment D_{after}= distance between stops after the improvement/investment $D_{before,com}$ = distance between stops before the improvement/investment for disadvantaged communities $D_{after,com}$= distance between stops after the improvement/investment for disadvantaged communities	$Output\ 1 = \left(\frac{D_{before} - D_{after}}{D_{before}}\right) \times 100$ $Output\ 2 = \left(\frac{D_{before,com} - D_{after,com}}{D_{before},com}\right) \times 100$

	Number of vehicles purchased being ADA-compliant	N_{before} = number of ADA-complaint vehicles before the improvement/investment N_{after}= number of ADA-complaint vehicles after the improvement/investment	$Output\ 1 = \left(\frac{N_{after} - N_{before}}{N_{before}}\right) \times 100$
	Difference in total number of riders served between immediate improvement stops before and after the project	r_{before} = riders served between immediate improvement stops before the improvement/investment r_{after}= riders served between immediate improvement stops after the improvement/investment	$Output\ 1 = \left(\frac{r_{after} - r_{before}}{r_{before}}\right) \times 100$
	Increase in stop-level accessibility along the route	$StopAccess_{before}$ = population or jobs accessible around stops before the improvement/investment $StopAccess_{after}$= population or jobs accessible around stops after the improvement/investment	$Output\ 1 = \left(\frac{StopAccess_{after} - StopAccess_{before}}{StopAccess_{before}}\right) \times 100$

	Ridership and boarding counts along the route (before and after the project)	$ridership_{before}$ = ridership or boarding along the route before the improvement/investment $ridership_{after}$= ridership or boarding along the route after the improvement/investment	$Output\ 1 = \left(\frac{ridership_{after} - ridership_{before}}{ridership_{before}}\right) \times 100$
	Determine stop productivity	$prod_{before}$ = number of riders using the closest stop before the improvement/investment $prod_{after}$= number of riders using the closest stop after the improvement/investment	$Output\ 1 = \left(\frac{prod_{after} - prod_{before}}{prod_{before}}\right) \times 100$
	Number of stations by ADA accessibility	ADA_{before} = number of stations that are ADA-complaint before the improvement/investment ADA_{after} = number of stations that are ADA-complaint after the improvement/investment	$Output\ 1 = \left(\frac{ADA_{after} - ADA_{before}}{ADA_{before}}\right) \times 100$

	Ability to reach goods, services, and activities (coverage of transit services)	$Reach_{before}$ = activities such as employment centers reached before the improvement/investment $Reach_{after}$= activities such as employment centers reached after the improvement/investment	$Output\ 1 = \left(\frac{Reach_{after} - Reach_{before}}{Reach_{before}}\right) \times 100$
	Percentage of population within given miles of transit line	$Pop_{before,m}$ = population within given miles, *m*, of the transit line before the improvement/investment $Pop_{after,m}$= population within given miles, *m*, of the transit line after the improvement/investment	$Output\ 1 = \left(\frac{pop_{after,m} - pop_{before,m}}{pop_{before,m}}\right) \times 100$
	Percentage of population within given miles of transit stations	$PopPer_{before,m}$ = population percentage within given miles, *m*, before the improvement/investment $PopPer_{after,m}$= population percentage within given miles, *m*, after the improvement/investment	$Output\ 1 = \left(\frac{PopPer_{after,m} - PopPer_{before,m}}{PopPer_{before,m}}\right) \times 100$

	Percentage of rural counties with public transit service	$RuralCo_{before}$ = percentage of rural counties served by rail before the improvement/investment $RuralCo_{after}$= percentage of rural counties served by rail after the improvement/investment	$Output\ 1 = \left(\frac{RuralCo_{after} - RuralCo_{before}}{RuralCo_{before}}\right) \times 100$
	Percentage of rural population with transit service	$RuralPo_{before}$ = percentage of rural population served by rail before the improvement/investment $RuralPo_{after}$= percentage of rural population served by rail after the improvement/investment	$Output\ 1 = \left(\frac{RuralPo_{after} - RuralPo_{before}}{RuralPo_{before}}\right) \times 100$
	Number of residents, major employers or schools served within one-quarter mile of a transit stop	Num_{before} = number of residents served within one-quarter mile of a transit stop before the improvement/investment Num_{after} = number of residents served within one-quarter mile of a transit stop after the improvement/investment	$Output\ 1 = \left(\frac{Num_{after} - Num_{before}}{Num_{before}}\right) \times 100$

		Emp_{before} = number of employers served within one-quarter mile of a transit stop before the improvement/investment Emp_{after} = number of employers served within one-quarter mile of a transit stop after the improvement/investment	$Output\ 2 = \left(\frac{Emp_{after} - Emp_{before}}{Emp_{before}}\right) \times 100$
		Sch_{before} = number of schools served within one-quarter mile of a transit stop before the improvement/investment Sch_{after} = number of schools served within one-quarter mile of a transit stop after the improvement/investment	$Output\ 3 = \left(\frac{Sch_{after} - Sch_{before}}{Sch_{before}}\right) \times 100$
	Number of transit stops	$TransitStops_{before}$ = number of transit stops connected before the improvement/investment $TransitStops_{after}$ = number of transit stops connected after the improvement/investment	$Output\ 1 = \left(\frac{TransitStops_{after} - TransitStops_{before}}{TransitStops_{before}}\right) \times 100$

	Number of intermodal stations	$InterStations_{before}$ = number of intermodal stations connected before the improvement/investment $InterStations_{after}$ = number of intermodal stations connected after the improvement/investment	$Output\ 1 = \left(\frac{InterStations_{after} - InterStations_{before}}{InterStations_{before}}\right) \times 100$

Table II: Formulation for quantifying cost measure

Measure	*Metric*	*Definition*	*Quantified Output*
Costs	Operating costs	$Oper_{before}$ = rail operating cost before the improvement/investment $Oper_{after}$ = rail operating cost after the improvement/investment	$Output\ 1 = \left(\frac{Oper_{before} - Oper_{after}}{Oper_{before}}\right) \times 100$
	Asset life cost	$Asset_{before}$ = asset life cost before the improvement/investment $Asset_{after}$ = asset life cost after the improvement/investment	$Output\ 1 = \left(\frac{Asset_{before} - Asset_{after}}{Asset_{before}}\right) \times 100$

	Cost per revenue hour	$CostperRev_{before}$ = rail operating cost per revenue before the improvement/investment $CostperRev_{after}$ = rail operating cost per revenue after the improvement/investment	$Output\ 1 = \left(\frac{CostperRev_{before} - CostperRev_{after}}{CostperRev_{before}}\right) \times 100$
	Capital budget and expenditures	$CapExp_{before}$ = capital expenditures before the improvement/investment $CapExp_{after}$ = capital expenditures after the improvement/investment	$Output\ 1 = \left(\frac{CapExp_{before} - CapExp_{after}}{CapExp_{before}}\right) \times 100$
	Operating cost per revenue hour	$OperRevHour_{before}$ = operating cost per revenue hour before the improvement/investment $OperRevHour_{after}$ = operating cost per revenue hour after the improvement/investment	$Output\ 1 = \left(\frac{OperRevHour_{before} - OperRevHour_{after}}{OperRevHour_{before}}\right) \times 100$
	Operating cost per revenue mile	$OperRevMile_{before}$ = operating cost per revenue mile before the improvement/investment $OperRevMile_{after}$ = operating cost per revenue mile after the improvement/investment	$Output\ 1 = \left(\frac{OperRevMile_{before} - OperRevMile_{after}}{OperRevMile_{before}}\right) \times 100$
	Opportunity cost per passenger – calculated based on delay and	$OpprCost_{before}$ = opportunity cost per passenger before the improvement/investment	

	Bureau of Economic Analysis of industrial rates.	$OpprCost_{after}$ = opportunity cost per passenger after the improvement/investment	$Output\ 1 = \left(\frac{OpprCost_{before} - OpprCost_{after}}{OpprCost_{before}}\right) \times 100$
	Maintenance cost	$MaintCost_{before}$ = maintenance cost before the improvement/investment $MaintCost_{after}$ = maintenance cost after the improvement/investment	$Output\ 1 = \left(\frac{MaintCost_{before} - MaintCost_{after}}{MaintCost_{before}}\right) \times 100$
	Labor cost	$LobCost_{before}$ = labor cost before the improvement/investment $LabCost_{after}$ = labor cost after the improvement/investment	$Output\ 1 = \left(\frac{LabCost_{before} - LabCost_{after}}{LabCost_{before}}\right) \times 100$
	Vehicle miles (hours) per revenue mile (or hour)	$VehMiles_{before}$ = vehicle miles per revenue (mile or hour) before the improvement/investment $VehMiles_{after}$ = vehicle miles per revenue (mile or hour) per after the improvement/investment $VehHours_{before}$ = vehicle hours per revenue (mile or hour) per before the improvement/investment	$Output\ 1 = \left(\frac{VehMiles_{before} - VehMiles_{after}}{VehMiles_{before}}\right) \times 100$ $Output\ 2 = \left(\frac{VehHours_{before} - VehHours_{after}}{VehHours_{before}}\right) \times 100$

		$VehHours_{after}$ = vehicle hours per revenue (mile or hour) per after the improvement/investment	
	Operating cost per peak vehicle in service	$OperCostPeak_{before}$ = operating cost per peak vehicle in service before the improvement/investment $OperCostPeak_{after}$ = operating cost per peak vehicle in service after the improvement/investment	$Output\ 1 = \left(\frac{OperCostPeak_{before} - OperCostPeak_{after}}{OperCostPeak_{before}}\right) \times 100$
	Farebox recovery ratio	$FareBox_{before}$ = farebox recovery ratio before the improvement/investment $FareBox_{after}$ = farebox recovery ratio after the improvement/investment	$Output\ 1 = \left(\frac{FareBox_{after} - FareBox_{before}}{FareBox_{before}}\right) \times 100$
	Operating cost per boarding	$OperCostBoard_{before}$ = operating cost per boarding before the improvement/investment $OperCostBoard_{after}$ = operating cost per boarding after the improvement/investment	$Output\ 1 = \left(\frac{OperCostBoard_{before} - OperCostBoard_{after}}{OperCostBoard_{before}}\right) \times 100$

	Operating cost per passenger-mile	$OperCostPass_{before}$ = operating cost per passenger mile before the improvement/investment $OperCostPass_{after}$ = operating cost per passenger mile after the improvement/investment	$Output\ 1 = \left(\frac{OperCostBoard_{before} - OperCostBoard_{after}}{OperCostBoard_{before}}\right) \times 100$
	Operating cost per service area capita	$OperCostSer_{before}$ = operating cost per service area capita before the improvement/investment $OperCostSer_{after}$ = operating cost per service area capita after the improvement/investment	$Output\ 1 = \left(\frac{OperCostSer_{before} - OperCostSer_{after}}{OperCostSer_{before}}\right) \times 100$
	Cost per trip (or PMT, VMT)	$CoPMT_{before}$ = cost per passenger-miles traveled before the improvement/investment $CoPMT_{after}$ = cost per passenger-miles traveled after the improvement/investment $CoVMT_{before}$ = cost per vehicle-miles traveled before the improvement/investment $CoVMT_{after}$ = cost per vehicle-miles traveled after the improvement/investment	$Output\ 1 = \left(\frac{CoPMT_{before} - CoPMT_{after}}{CoPMT_{before}}\right) \times 100$ $Output\ 2 = \left(\frac{CoVMT_{before} - CoVMT_{after}}{CoVMT_{before}}\right) \times 100$

	Number of vehicle system failures	$VehFail_{before}$ = number of vehicle system failures before the improvement/investment $VehFail_{after}$ = number of vehicle system failures after the improvement/investment	$Output\ 1 = \left(\frac{VehFail_{before} - VehFail_{after}}{VehFail_{before}}\right) \times 100$
	Maintenance category cost/total maintenance cost	$Main_{before}$ = maintenance cost before the improvement/investment $Main_{after}$ = maintenance cost after the improvement/investment	$Output\ 1 = \left(\frac{Main_{before} - Main_{after}}{Main_{before}}\right) \times 100$
	Average annual maintenance cost per vehicle operated in maximum service	$AvgAnnMain_{before}$ = average annual maintenance cost before the improvement/investment $AvgAnnMain_{after}$ = average annual maintenance cost after the improvement/investment	$Output\ 1 = \left(\frac{AvgAnnMain_{before} - AvgAnnMain_{after}}{AvgAnnMain_{before}}\right) \times 100$
	Vehicle maintenance cost/vehicle (car) mile	$VehMain_{before}$ = vehicle maintenance cost before the improvement/investment $VehMain_{after}$ = vehicle maintenance cost after the improvement/investment	$Output\ 1 = \left(\frac{VehMain_{before} - VehMain_{after}}{VehMain_{before}}\right) \times 100$

	Non-vehicle maintenance cost/track mile	$OtherMain_{before}$ = non-vehicle maintenance cost per track mile before the improvement/investment $OtherVehMain_{after}$ = non-vehicle maintenance cost per track mile after the improvement/investment	$Output\ 1 = \left(\frac{OtherMain_{before} - OtherMain_{after}}{OtherMain_{before}}\right) \times 100$

Table III: Formulation for quantifying greenhouse gas emissions measure

Measure	Metric	Definition	Quantified Output
Greenhouse Gas (GHG) Emissions (and other criteria pollutants)	GHG emissions for cars and diesel fleets	$GHGemissions_{before}$ = total greenhouse gas emissions reductions (including criteria pollutants) before the improvement/investment $GHGemissions_{after}$ = total greenhouse gas emissions reductions (including criteria pollutants) after the improvement/investment	$Output\ 1 = \left(\frac{GHGemissions_{after} - GHGemissions_{before}}{GHGemissions_{before}}\right) \times 100$
	Fuel type of new versus displaced vehicles to assess	$FuelType_{before}$ = number of fuel type vehicles that reduce emissions before	$Output\ 1 = \left(\frac{FuelType_{after} - FuelType_{before}}{FuelType_{before}}\right) \times 100$

	reductions in GHG emissions	the improvement/investment $FuelType_{after}$ = number of fuel type vehicles that reduce emissions after the improvement/investment	
	Changes in service miles, hours and the amount of fuel consumed on an annual basis (includes diesel engines and trucks)	$ServiceMiles_{before}$ = service miles before the improvement/investment $ServiceMiles_{after}$ = service miles after the improvement/investment $ServiceHours_{before}$ = service hours before the improvement/investment $ServiceHours_{after}$ = service hours after the improvement/investment $FuelConsumed_{before}$ = fuel consumed before the improvement/investment	$Output\ 1 = \left(\frac{ServiceMiles_{before} - ServiceMiles_{after}}{ServiceMiles_{before}}\right) \times 100$ $Output\ 2 = \left(\frac{ServiceHours_{before} - ServiceHours_{after}}{ServiceHours_{before}}\right) \times 100$ $Output\ 3 = \left(\frac{FuelConsumed_{before} - FuelConsumed_{after}}{FuelConsumed_{before}}\right) \times 100$

		$FuelConsumed_{after}$ = fuel consumed after the improvement/investment	
	Vehicle fuel efficiency based on mile per gallon	$VehicleEff_{before}$ = vehicle efficiency (mile per gallon) before the improvement/investment $VehicleEff_{after}$ = vehicle efficiency (mile per gallon) after the improvement/investment	$Output\ 1 = \left(\frac{VehicleEff_{after} - VehicleEff_{before}}{VehicleEff_{before}}\right) \times 100$

Table IV: Formulation for quantifying land-use measure

Measure	*Metric*	*Definition*	*Quantified Output*
Land Use	Geographical dispersion (number of parcels connected across various land-use types such as industrial, commercial, residential, and agricultural)	$GeoDis_{before}$ = geographical dispersion before the improvement/investment $GeoDis_{after}$ = geographical dispersion before the improvement/investment	$Output\ 1 = \left(\frac{GeoDis_{after} - GeoDis_{before}}{GeoDis_{before}}\right) \times 100$

	Area compatibility for transit (or freight) projects (in terms of terrain)	$Compat_{before}$ = area compatibility before the improvement/investment (yes =1 or no =0) $Compat_{before}$ = area compatibility after the improvement/investment (yes =1 or no =0)	$Output\ 1 = \left(\frac{Compat_{after} - Compat_{before}}{Compat_{before}}\right) \times 100$

Table V: Formulation for quantifying mobility measure

Measure	*Metric*	*Definition*	*Quantified Output*
Mobility	Expansion of the transit fleet or transit network	$Fleet_{before}$ = fleet size before the improvement/investment $Fleet_{after}$ = fleet size after the improvement/investment $Network_{before}$ = network size in miles before the improvement/investment $Network_{after}$ = network size in miles after the improvement/investment	$Output\ 1 = \left(\frac{Fleet_{after} - Fleet_{before}}{Fleet_{before}}\right) \times 100$ $Output\ 2 = \left(\frac{Network_{after} - Network_{before}}{Network_{before}}\right) \times 100$

	Average speed	$RouteSpeed_{before}$ = average speed on the route before the improvement/investment $RouteSpeed_{after}$ = average speed on the route after the improvement/investment	$Output\ 1 = \left(\frac{RouteSpeed_{after} - RouteSpeed_{before}}{RouteSpeed_{before}}\right) \times 100$
	Ridership and boardings	$Ridership_{before}$ = ridership before the improvement/investment $Ridership_{after}$ = ridership after the improvement/investment	$Output\ 1 = \left(\frac{Ridership_{after} - Ridership_{before}}{Ridership_{before}}\right) \times 100$
	Number of passenger (or freight) trips for a project (route and service)	$PassFreightTrips_{before}$ = ridership before the improvement/investment $PassFreightTrips_{after}$ = ridership after the improvement/investment	$Output\ 1 = \left(\frac{PassFreightTrips_{after} - PassFreightTrips_{before}}{PassFreightTrips_{before}}\right) \times 100$

	Number of transit service hours	$TransitSerHrs_{before}$ = number of transit service hours before the improvement/investment $TransitSerHrs_{after}$ = number of transit service hours after the improvement/investment	$Output\ 1 = \left(\frac{TransitSerHrs_{after} - TransitSerHrs_{before}}{TransitSerHrs_{before}}\right) \times 100$
	Frequency of service on route	$FreqService_{before}$ = frequency of service on route before the improvement/investment $FreqService_{after}$ = frequency of service on route after the improvement/investment	$Output\ 1 = \left(\frac{FreqService_{after} - FreqService_{before}}{FreqService_{before}}\right) \times 100$
	Connectivity – Number of timed-transfer stops between intercity passenger rail and local bus transit service	$Transfers_{before}$ = number of timed-transfer stops between intercity passenger rail and local bus transit service before the improvement/investment $Transfers_{after}$ = number of timed-transfer stops between intercity	$Output\ 1 = \left(\frac{Transfers_{after} - Transfers_{before}}{Transfers_{before}}\right) \times 100$

		passenger rail and local bus transit service after the improvement/investment	
	Reliability – number of transit (or freight) trips on time	$Reliability_{before}$ = number of transit (or freight) trips on time before the improvement/investment $Reliability_{after}$ = number of transit (or freight) trips on time after the improvement/investment	$Output\ 1 = \left(\frac{Reliability_{after} - Reliability_{before}}{Reliability_{before}}\right) \times 100$
	Percent of fleet with wi-fi, on-board restrooms, and stations, waiting areas, agencies using real-time passenger information systems, etc.	$Comfort_{before}$ = percentage of fleet with wi-fi, on-board restrooms, and stations, waiting areas, agencies using real-time passenger information systems, etc. before the improvement/investment $Comfort_{after}$ = percentage of fleet with wi-fi, on-board restrooms, and stations, waiting areas, agencies using real-time passenger information systems, etc.	$Output\ 1 = \left(\frac{Comfort_{after} - Comfort_{before}}{Comfort_{before}}\right) \times 100$

		after the improvement/investment	
	Total passenger-miles (or freight car miles)	$PassFreightMiles_{before}$ = passenger- miles (or freight car miles) before the improvement/investment $PassTransit_{after}$ = passenger- miles (or freight car miles) after the improvement/investment	$Output\ 1 = \left(\frac{PassFreightMiles_{after} - PassFreightMiles_{before}}{PassFreightMiles_{before}}\right) \times 100$

Table VI: Formulation for quantifying safety and security measure

Measure	*Metrics*	*Definition*	*Quantified Output*
Safety and Security	Key performance indicators (KPIs) related to safety such as accidents	$PreventAcc_{before}$ = accidents before the improvement/investment $PreventAcc_{after}$ = accidents after the improvement/investment	$Output\ 1 = \left(\frac{PreventAcc_{after} - PreventAcc_{before}}{PreventAcc_{before}}\right) \times 100$

	Operator safety in terms of traffic level, lighting, and other factors	$Lighting_{before}$ = lighting intensity before the improvement/investment $Lighting_{after}$ = lighting intensity after the improvement/investment	$Output\ 1 = \left(\frac{Lighting_{after} - Lighting_{before}}{Lighting_{before}}\right) \times 100$
	Number of accident reports and problem calls	$AccReprt_{before}$ = number of accident reports and problem calls before the improvement/investment $AccReprt_{after}$ = number of accident reports and problem calls after the improvement/investment	$Output\ 1 = \left(\frac{AccReprt_{before} - AccReprt_{after}}{AccReprt_{before}}\right) \times 100$
	Number of incidents (per VMT, per Year, per 1,000 passenger trips)	$Incidents_{before}$ = number of incidents (per VMT, per year, per 1,000 passenger trips) before the improvement/investment $Incidents_{after}$ = number of incidents (per VMT, per year, per 1,000 passenger trips) after the improvement/investment	$Output\ 1 = \left(\frac{Incidents_{before} - Incidents_{after}}{Incidents_{before}}\right) \times 100$

	Percentage of rolling stock with safety features (driver cam, passenger cameras, equipment, etc.)	$RollingSafe_{before}$ = percentage of rolling stock with safety features (driver cam, passenger cameras, equipment, etc.) before the improvement/investment $RollingSafe_{after}$ = percentage of rolling stock with safety features (driver cam, passenger cams, equipment, etc.) after the improvement/investment	$Output\ 1 = \left(\frac{RollingSafe_{before} - RollingSafe_{after}}{RollingSafe_{before}}\right) \times 100$
	Percentage of at-grade crossings with active warning protection	$AtGradeWarn_{before}$ = percentage of at-grade crossings with active warning protection before the improvement/investment $AtGradeWarn_{after}$ = percentage of at-grade crossings with active warning protection after the improvement/investment	$Output\ 1 = \left(\frac{AtGradeWarn_{after} - AtGradeWarn_{before}}{AtGradeWarn_{before}}\right) \times 100$

	Percentage of passenger rail stops/transfer points/stations with security features such as lighting, security staff, or CCTV	$RailStopsSec_{before}$ = percentage of passenger rail stops/transfer points/stations with security features such as lighting, security staff, or CCTV before the improvement/investment $RailStopsSec_{after}$ = percentage of passenger rail stops/transfer points/stations with security features such as lighting, security staff, or CCTV after the improvement/investment	$Output\ 1 = \left(\frac{RailStopsSec_{after} - RailStopsSec_{before}}{RailStopsSec_{before}}\right) \times 100$
	Casualty and liability cost per vehicle mile	$CasCost_{before}$ = casualty and liability cost per vehicle mile before the improvement/investment $CasCost_{after}$ = casualty and liability cost per vehicle mile after the improvement/investment	$Output\ 1 = \left(\frac{CasCost_{before} - CasCost_{after}}{CasCost_{before}}\right) \times 100$

Table VII: Formulation for quantifying service quality measure

Measure	*Metrics*	*Definition*	*Quantified Output*
Service Quality	On-time arrival/departure at stations	$OnTimeArrDep_{before}$ = on-time arrival/departure at stations before the improvement/investment $OnTimeArrDep_{after}$ = on-time arrival/departure after the improvement/investment	$Output\ 1 = \left(\frac{OnTimeArrDep_{after} - OnTimeArrDep_{before}}{OnTimeArrDep_{before}}\right) \times 100$
	Number of complaints by the rider (satisfaction level)	$NumCompl_{before}$ = number of complaints before the improvement/investment $NumCompl_{after}$ = number of complaints after the improvement/investment	$Output\ 1 = \left(\frac{NumCompl_{after} - NumCompl_{before}}{NumCompl_{before}}\right) \times 100$

	Schedule adherence	$Schedule_{before}$ = number of on-schedule arrivals/departures at the station before the improvement/investment $Schedule_{after}$ = number of on-schedule arrivals/departures at the station after the improvement/investment	$Output\ 1 = \left(\frac{Schedule_{after} - Schedule_{before}}{Schedule_{before}}\right) \times 100$
	Excess wait times at stations (delay)	$ExcessWait_{before}$ = excess wait time at station (or delay) before the improvement/investment $ExcessWait_{after}$ = excess wait time at station (or delay) after the improvement/investment	$Output\ 1 = \left(\frac{ExcessWait_{after} - ExcessWait_{before}}{ExcessWait_{before}}\right) \times 100$
	Call-center response time	$Call_{before}$ = call-center response time before the improvement/investment $Call_{after}$ = call-center response time after the improvement/investment	$Output\ 1 = \left(\frac{Call_{before} - Call_{after}}{Call_{before}}\right) \times 100$

	Missed service trips	$Missed_{before}$ = number of missed service trips before the improvement/investment $Missed_{after}$ = number of missed service trips after the improvement/investment	$$Output\ 1 = \left(\frac{Missed_{before} - Missed_{after}}{Missed_{before}}\right) \times 100$$
	Revenue miles (hours)	$RevMilesCap_{before}$ = revenue miles before the improvement/investment $RevMilesCap_{after}$ = revenue miles after the improvement/investment $RevHoursCap_{before}$ = revenue hours before the improvement/investment $RevHoursCap_{after}$ = revenue hours after the improvement/investment	$$Output\ 1 = \left(\frac{RevMiles_{after} - RevMiles_{before}}{RevMiles_{before}}\right) \times 100$$ $$Output\ 2 = \left(\frac{RevHours_{after} - RevHours_{before}}{RevMiles_{before}}\right) \times 100$$

	Percent of fleet with ramps/low-floor and other amenities	$FleetAmen_{before}$ = percent of fleet with ramps/low-floor and other amenities before the improvement/investment $FleetAmen_{after}$ = percent of fleet with ramps/low-floor and other amenities after the improvement/investment	$Output\ 1 = \left(\frac{FleetAmen_{after} - FleetAmen_{before}}{FleetAmen_{before}}\right) \times 100$

Table VIII: Formulation for quantifying travel time measure

Measure	*Metrics*	*Definition*	*Quantified Output*
Travel Time	Scheduled times versus equivalent auto travel times	$SchedEqui_{before}$ = ratio of schedule times versus equivalent auto travel times before the improvement/investment $SchedEqui_{after}$ = ratio of schedule times versus equivalent auto travel times after the improvement/investment	$Output\ 1 = \left(\frac{SchedEqui_{before} - SchedEqui_{after}}{SchedEqui_{before}}\right) \times 100$

	Frequency of on-time arrivals/departures	$FreqOnArr_{before}$ = frequency of on-time arrivals at a station before the improvement/investment $FreqOnArr_{after}$ = frequency of on-time arrivals at a station after the improvement/investment $FreqOnDep_{before}$ = frequency of on-time departures at a station before the improvement/investment $FreqOnDep_{after}$ = frequency of on-time departures at a station after the improvement/investment	$Output\ 1 = \left(\frac{FreqOnArr_{after} - FreqOnArr_{before}}{FreqOnArr_{before}}\right) \times 100$ $Output\ 2 = \left(\frac{FreqOnDep_{after} - FreqOnDep_{before}}{FreqOnDep_{before}}\right) \times 100$

Table IX: Formulation for quantifying economic measure

Measure	*Employment - Metrics*	*Definition*	*Quantified Output*
Economic Development	Workers employed by transit agencies (direct, indirect and induced)	$Employed_{before}$ = number of workers employed before the improvement/investment $Employed_{after}$ = number of workers employed after the improvement/investment	$Output\ 1 = \left(\frac{Employed_{after} - Employed_{before}}{Employed_{before}}\right) \times 100$
	Number/Percentage of jobs/businesses/terminals served by rail	$JobsPer_{before}$ = percentage of jobs served by rail before the improvement/investment $JobsPer_{after}$ = percentage of jobs served by rail after the improvement/investment $JobsNum_{before}$ = number of jobs served by rail before the improvement/investment $JobsNum_{after}$ = number of jobs served by rail after the improvement/investment $BusinessNum_{before}$ = number of businesses	$Output\ 1 = \left(\frac{JobsPer_{after} - JobsPer_{before}}{JobsPer_{before}}\right) \times 100$ $Output\ 2 = \left(\frac{JobsNum_{after} - JobsNum_{before}}{JobsPer_{before}}\right) \times 100$ $Output\ 3 = \left(\frac{BusinessNum_{after} - BusinessNum_{before}}{BusinessNum_{before}}\right) \times 100$ $Output\ 4 = \left(\frac{BusinessPer_{after} - BusinessPer_{before}}{BusinessPer_{before}}\right) \times 100$

		served by rail before the improvement/investment $BusinessNum_{after}$ = number of businesses/terminals served by rail after the improvement/investment $BusinessPer_{before}$ = percentage of businesses/terminals served by rail before the improvement/investment $BusinessPer_{after}$ = percentage of businesses served by rail after the improvement/investment	

Table X: Formulation for quantifying resource utilization measure

Measure	*Metric*	*Definition*	*Quantified Output*
Resource Utilization *(is defined as a means for transit agencies to reduce costs and other operational expenditures for fleet)*	Vehicle hours per vehicle operated in peak service	$VehHr_{before}$ = vehicle hours per vehicle operated in peak service before the improvement/investment $VehHr_{after}$ = vehicle hours per vehicle operated in peak service after the improvement/investment	$Output\ 1 = \left(\frac{VehHr_{before} - VehHr_{after}}{VehHr_{before}}\right) \times 100$
	Vehicle miles per vehicle operated in peak service	$VehMi_{before}$ = vehicle miles per vehicle operated in peak service before the improvement/investment $VehMi_{after}$ = vehicle miles per vehicle operated in peak service after the improvement/investment	$Output\ 1 = \left(\frac{VehMi_{before} - VehMi_{after}}{VehMi_{before}}\right) \times 100$

	Revenue hours per employee full-time equivalent	$RevHrsEmpl_{before}$ = revenue hours per employee full-time equivalent before the improvement/investment $RevHrsEmpl_{after}$ = revenue hours per employee full-time equivalent after the improvement/investment	$Output\ 1 = \left(\frac{RevHrsEmpl_{after} - RevHrsEmpl_{before}}{RevHrsEmpl_{before}}\right) \times 100$
	Vehicle (or rail) miles per gallon of fuel consumed	$VehMiFuel_{before}$ = vehicle miles per gallon of fuel consumed before the improvement/investment $VehMiFuel_{after}$ = vehicle miles per gallon of fuel consumed after the improvement/investment	$Output\ 1 = \left(\frac{VehMiFuel_{before} - VehMiFuel_{after}}{VehMiFuel_{before}}\right) \times 100$
	Vehicle miles per kilowatt-hour of power consumed (energy savings)	$VehMikW_{before}$ = vehicle miles per kilowatt-hour of power consumed before the improvement/investment $VehMikW_{after}$ = vehicle miles per kilowatt-hour of power consumed after the improvement/investment	$Output\ 1 = \left(\frac{VehMikW_{before} - VehMikW_{after}}{VehMikW_{before}}\right) \times 100$

	Revenue hours per vehicle operated in peak service	$RevHrVeh_{before}$ = revenue hours per vehicle operated in peak service before the improvement/investment $RevHrVeh_{after}$ = revenue hours per vehicle operated in peak service after the improvement/investment	$Output\ 1 = \left(\frac{RevHrVeh_{after} - RevHrVeh_{before}}{RevMiVeh_{before}}\right) \times 100$
	Revenue miles per vehicle operated in peak service	$RevMiVeh_{before}$ = revenue miles per vehicle operated in peak service before the improvement/investment $RevMiVeh_{after}$ = revenue miles per vehicle operated in peak service after the improvement/investment	$Output\ 1 = \left(\frac{RevMiVeh_{after} - RevMiVeh_{before}}{RevMiVeh_{before}}\right) \times 100$