Case Studies of Socio-Economic and Environmental Life Cycle Assessment of Complete Streets

June 2022

A Research Report from the National Center for Sustainable Transportation

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16. Abstract

"Complete streets" is a design concept for primarily urban streets and intersections (existing and/or new) intended to encourage active transportation by bicyclists and pedestrians by making streets safer, convenient, and attractive for active transportation; motorized transportation and parking are also accommodated in the design concept. The social and economic performance indicators included in the social life cycle assessment (SLCA) framework that was used in this project provide a great deal of insight into specific and different potential benefits of a given complete streets project. The SLCA framework is based on five categories of concerns and 17 performance measures or indicators. The indicators were tested in the project and evaluated for final recommendations for use in future studies. The results are compared with the existing streets that were configured to be vehicle-centric. The case studies were solicited in more and less advantaged neighborhoods so that the framework could also be evaluated in different contexts. Use of the CalEnviroScreen tool from the California Environmental Protection Agency was also investigated to assess the exposure of neighborhoods and their vulnerability to environmental impacts in conjunction with the performance indicators when evaluating the potential benefits for disadvantaged neighborhoods (also called priority population areas). As was found in the preceding study, the primary environmental impacts come from the use stage, namely changes in vehicle travel and changes in vehicle speeds from complete street design features. Recommendations are made for dropping some indicators because of difficulties collecting data or interpreting the results, modifications of other indicators, and adding some new indicators to fill important gaps.

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EXECUTIVE SUMMARY

Complete Streets policies guide planning in communities by making the transportation system accommodating to all users including vehicle drivers, pedestrians, and bicyclists, as well as those using public transportation. Complete streets policies are also strategies for building healthy and safe community environments that support active living. The benefits of complete streets have been identified as increased transportation choices, economic revitalization, improved return on infrastructure investments, livable communities, improved safety, more walking and bicycling to improve public health, greenhouse gas (GHG) reduction, and improved air quality.

Life cycle assessment (LCA) is a holistic approach in which the environmental sustainability of a product, project, process, or system can be assessed and quantified. Environmental LCAs quantify the energy, resource use, and emissions to air, water, and land for a product or a system. One gap that has been identified in current LCA impact indicators is the lack of socio-economic indicators to complement the existing environmental indicators. Social LCAs quantify the social and sociological aspects that are related to a system. A preceding study by the same research team developed a framework for LCA of complete streets projects, including development of social and economic performance indicators that were adapted from previous research by others. Social life cycle assessment (S-LCA) can also help understand the processes that decide where complete street projects get built, what goals they are designed to achieve, whether they are beneficial, and determine who receives such benefits.

The research arc that this project is a part of seeks to provide a scientific method for evaluating the potential benefits or disadvantages of a complete streets project. Impacting the development of any method to evaluate publicly funded transportation improvements are Title VI of the Civil Rights Act of 1964 and Executive Order 12898, known as Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Population, issued by President Clinton in 1984.

According to the US EPA, the purpose of these policies is to focus federal attention on the environmental and human health effects of federal actions on minority and low-income populations with the goal of achieving environmental protection for all communities. More specifically, the executive order is intended to promote nondiscrimination in Federal programs substantially affecting human health and the environment. Transportation projects, such as publicly funded complete streets projects, fall under the umbrella of Executive Order 12898 as well as Title VI. State, regional, and local government agencies are required to identify and address the disproportionately high and adverse human health or environmental effects of their actions on minority and low-income populations. Such prevention activities can help ensure that all communities and persons live in a safe and healthful environment by identifying

and correcting adverse conditions, especially in low-income communities from being subject to disproportionately high and adverse environmental effects.

Although, Federal, State, and local funding agencies overseeing public infrastructure investment pay close attention to the provisions of Title VI and Executive Order 12898, little to no information is provided on how to meet these requirements. This Complete Streets SLCA model is an attempt to add to our knowledge of how complete streets projects can assist transportation planners in moving towards achieving environmental protection for minority and low-income populations. The model incorporates a number of indicators on social well-being using data sources on local socioeconomic conditions. Through this process, the Complete Streets SLCA demonstrates how a more rigorous analysis can inform environmental justice concerns in minority and low-income neighborhoods by helping us respond to three basic questions:

- Does the project cause harm, in particular to a legislatively designated disadvantaged area/priority investment area?[1]
- Does the project benefit a legislatively designated disadvantaged area/priority investment area?
- Does the project improve access to the social determinants of health and/or community destinations that help manage social determinants?

The purpose of the project presented in this report is to test the complete streets LCA framework by using it to quantify the environmental and social impacts of complete streets through three case studies. The results are compared with the existing streets that were configured to be vehicle-centric. The case studies were solicited in more and less advantaged neighborhoods so that the framework could also be evaluated in different contexts. The case studies also include one project each in urban, suburban, and rural areas. Case study evaluation was based on the project design for those that had not yet been started or completed. Where the case study project had been completed, the project was evaluated based on performance before and after project completion.

The primary purpose of the case studies was to evaluate the efficacy of the performance measures proposed in the previous project regarding reasonableness of the results and the practicalities and difficulties of using them with the intent to provide a recommended final set of indicators. The indicators were also tested for their consideration of the size of the performance improvement rather than the final outcome so that projects in neighborhoods that start with low performance indicator values and have large improvement compare in ranking with projects in neighborhoods that start with good indicator values. This follows the approach described in the previous report. The second purpose was to evaluate complete streets in different contexts and see what kinds of benefits the indicators identified, and where

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[1] Note that the term “disadvantaged areas” or “disadvantaged neighborhoods is used extensively in this report. Terminology is changing and the same areas may also be called “priority population areas/neighborhoods” or “priority investment areas/neighborhoods” with similar although not necessarily the exactly the same meaning.

the indicators did not identify benefits. The third purpose was to advance the use of quantitative tools to help measure the success of a complete streets project to promote the most increase in the use active transportation as part of mobility to safely access locations of interest using active transportation and active transportation with transit.

The social and economic performance indicators included in the social LCA (SLCA) framework that was used in this project provide a great deal of insight into specific and different potential benefits of a given complete streets project. The SLCA framework is based on five categories of concerns and 17 performance measures or indicators. They span the range of benefits typically expressed as being desirable for a neighborhood, and potentially coming from a complete street. Examining the likely changes in these indicators from the complete street projects provides a more holistic view of each project, its likely benefits, and potential for social and/or economic harm and ineffectiveness, than would otherwise be possible. Although other benefits, such as a "sense of place" and neighborhood pride are not measurable, the majority of the expressed purposes for building a complete street can be evaluated. In particular, even if all complete streets projects provide benefits, calculation of the relative size of the changes in beneficial outcomes is now possible.

The main challenges in this social LCA (SLCA) study were data collection and the inherent context-specific and qualitative nature of social aspects of each complete street project. The evaluations of performance measures have been interpreted and discussed for each case study separately. The results summary of all the performance measures quantified for the three case studies were presented in Table 78, Table 79, and Table 80. The report includes evaluation of all indicators for difficulty of data collection, difficulty of calculation, difficulty of interpretation, and ability to consider change in performance as part of complete streets evaluation.

Table 106 shows the degree of difficulty of data collection and use of the methodology for each performance measure in the initial framework, and the final recommended and not recommended performance measures, based on the three case studies. The reasons for difficulty in data collection, methodology, or performance change interpretation for each performance measure were explained in each case study's section and are summarized in Table 106.

As was found in the preceding study, the primary environmental impacts come from the use stage. Any changes in vehicle travel (vehicle miles traveled, VMT) will have a relatively large impact on environmental impacts as long as the vehicle fleet remains primarily dependent on internal combustion engines. The effects of reduction in vehicle speeds from complete street design features are somewhat more complex than they appear in the analysis in this report. Reductions in speed at speeds below 45 miles per hour may increase fuel use and emissions for longer blocks. This is an area that needs more detailed drive cycle study.

The framework developed in the previous project did not include a method for considering environmental justice concerns in minority and low-income neighborhoods and was not able to answer the three questions posed above regarding harm, benefits and improved access in legislatively designated disadvantaged area/priority investment areas. For this project, the framework was expanded through the use of the CalEnviroScreen tool from the California Environmental Protection Agency to assess the exposure of neighborhoods and their vulnerability to environmental impacts in conjunction with the performance indicators. Other tools similar to CalEnvironScreen can be used with the framework.

Chapter 1: Introduction

Streets are shared public spaces whose functionality should safely accommodate motorized traffic, active transportation (bicycling and walking), and transit travel (NACTO, 2015). Additionally, complete streets designs should create economic benefits, and provide cultural and social spaces. Complete streets can fulfill different movement, environmental, and place functions, dependent on the street's type classification and the priorities for its functionality (Hui et al., 2018). Complete Streets policies guide planning in communities by making the transportation system accommodating to all users including vehicle drivers, pedestrians, and bicyclists, as well as those using public transportation. Complete streets policies are also strategies for building healthy and safe community environments that support active living (Moreland-Russell, 2013). . The benefits of complete streets as identified as increased transportation choices, economic revitalization, improved return on infrastructure investments, livable communities, improved safety, more walking and bicycling to improve public health, greenhouse gas (GHG) reduction, and improved air quality ((NCSC, 2010; Pucher et al., 2010; SGA&NCSC, 2017, 2018, 2019 Caltrans, 2019). Movement of freight and emergency vehicles, and the required functionality of a street for specific types of these vehicles, should also be considered as important functions during multimodal commercial street planning and design, however these operators are often overlooked or viewed (NYSERDA, 2018).

Life cycle assessment (LCA) is a holistic approach in which the environmental sustainability of a product, project, process, or system can be assessed and quantified. Environmental LCAs quantify the energy, resource use, and emissions to air, water, and land for a product or a system. Social LCAs quantify the social and sociological aspects that are related to a system. The advantage of using an LCA methodology is that it is a systems approach, with system boundaries depending on the goal of the assessment study, and because it considers the life cycle to account for long-term impacts rather than only initial outcomes. One gap that has been identified in current LCA impact indicators is the lack of socio-economic indicators to complement the existing environmental indicators (Evans et al., 2008; Rosenbaum, 2014). Social life cycle assessment (S-LCA) can also help understand the processes that decide where complete street projects get built, what goals they are designed to achieve, whether they are beneficial, and determine who receives such benefits.

Harvey et al (2018), identified that, to that date, the quantitative and context-relevant approach of LCA has not been used to assess the conversion of conventional streets to complete streets. Thus, a framework for LCA of complete streets projects was developed (Harvey et al., 2018). The framework addresses the gaps in socio-economic performance metrics and is intended to answer questions related to the funding of complete streets in terms of quantitative performance measures.

The research arc that includes the 2018 project and the project described in this report seeks to develop a scientific method for evaluating the potential benefits or disadvantages of a complete streets project. Impacting the development of any method to evaluate publicly funded transportation improvements are Title VI of the Civil Rights Act of 1964 and Executive

Order 12898, known as Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Population, issued by President Clinton in 1984.

According to the US EPA, the purpose of these policies is to focus federal attention on the environmental and human health effects of federal actions on minority and low-income populations with the goal of achieving environmental protection for all communities. More specifically, the executive order is intended to promote nondiscrimination in Federal programs substantially affecting human health and the environment. Transportation projects, such as publicly funded complete streets projects, fall under the umbrella of Executive Order 12898 as well as Title VI. State, regional, and local government agencies are required to identify and address the disproportionately high and adverse human health or environmental effects of their actions on minority and low-income populations. Such prevention activities can help ensure that all communities and persons live in a safe and healthful environment by identifying and correcting adverse conditions, especially in low-income communities from being subject to disproportionately high and adverse environmental effects.

Although, Federal, State, and local funding agencies overseeing public infrastructure investment pay close attention to the provisions of Title VI and Executive Order 12898, little to no information is provided on how to meet these requirements. This Complete Streets SLCA model is an attempt to add to our knowledge of how complete streets projects can assist transportation planners in moving towards achieving environmental protection for minority and low-income populations. The model incorporates a number of indicators on social well-being using data sources on local socioeconomic conditions. Through this process, the Complete Streets SLCA demonstrates how a more rigorous analysis can inform environmental justice concerns in minority and low-income neighborhoods by helping us respond to three basic questions:

- Does the project cause harm – in particular to a legislatively designated disadvantaged area/priority investment area?
- Does the project benefit a legislatively designated disadvantaged area/priority investment area?
- Does the project improve access to the social determinants of health and/or community destinations that help manage social determinants?

The framework developed in the previous project did not include a method for considering environmental justice concerns in minority and low-income neighborhoods and was not able to answer the three questions posed above regarding harm, benefits and improved access in legislatively designated disadvantaged area/priority investment areas. For this project, the framework was expanded through the use of the CalEnviroScreen tool from the California Environmental Protection Agency to assess the exposure of neighborhoods and their vulnerability to environmental impacts in conjunction with the performance indicators. Other tools similar to CalEnvironScreen can be used with the framework.

Funding to create complete streets is increasing in some locations. There is dedicated funding for complete streets in the California Road Repair and Accountability Act of 2017 (SACOG, undated). The federal Bipartisan Infrastructure Bill of 2021 includes new funding for bicycling and walking, as well as first ever requirements for states to address bicycling and walking safety and to write complete streets policies and plans (LAB, 2021). An unpassed bill in the US House of Representatives would require states to provide grant for design and construction of complete streets (Complete Streets Act of 2021). As funding increases, the processes by which complete streets are located and funded have become more important. Issues that have come to the forefront include the processes and metrics for prioritizing and awarding investments in transportation infrastructure, including complete streets. Some of the issues that exist are the processes that decide where complete street projects get built, what goals they are designed to achieve, and whether they are beneficial or disruptive, including contributing to the displacement of existing residents, particularly in disadvantaged communities.

The purpose of the project presented in this report is to test the complete streets LCA framework developed by Harvey et al (2018) by using it to quantify the environmental and social impacts of complete streets through three case studies. The results are compared with the existing streets that were configured to be vehicle-centric. To test the framework, case studies were solicited in both high and low resource neighborhoods on corridors in three cities with different infrastructure and socio-economic characteristics. This allowed the researchers to evaluate changes in how users of complete street improvements gain access to public resources and how and where public infrastructure investments are deployed. Of particular interest is understanding how complete streets projects can facilitate access to publicly managed social determinants of health that affect access to opportunity and social mobility.

Case study evaluation was based on the project design for those that had not yet been started or completed. Where the case study project had been completed, the project was evaluated based on performance before and after project completion.

Complete streets are expected to benefit all neighborhoods, contingent on how well they are designed. The expected outcomes from this study are comparisons of how the change in performance indicators in the framework differ in value for complete streets projects in disadvantaged and well-resourced neighborhoods, and to see if use of SLCA can help identify opportunities for infrastructure investment that can help move distressed neighborhoods towards economic productivity and social mobility. Complete streets can create access or improve existing access to social determinants, which in turn creates access to opportunity.

Chapter 2 of this report presents an overview of major documents related to LCA and social LCA. Chapter 3 presents an overview of the three case studies. Chapter 4 documents the results of the social LCA analysis for the case studies, and Chapter 5 does the same for the environmental LCA analysis. Chapter 6 summarizes the lessons learned from the case studies, and recommendations for improvement of the framework.

Chapter 2: Literature Review: Summary and Updates

Scope of Literature Review

This literature review presented in this report covers any new complete streets (CS) design policy or guidelines, performance measures in complete street case studies, and environmental and socio-economic LCA of complete streets completed since 2018. A detailed literature review was performed in the earlier project (Harvey et al., 2018) and the current study primarily focuses on new policies and cases, and a brief summary of some of the major documents regarding SLCA considered in the 2018 literature review.

Best Practices for Neighborhood Planning

Without sufficient guidance on how to move from policy to practice, both agencies and neighborhoods are vulnerable to reliance on community engagement as a proxy for sound urban planning (Hernandez 2021). The development, and in this report the testing, of a framework of quantitative outcome-based environmental and social performance measures for complete streets project evaluation combined with neighborhood vulnerability and exposure information (such as is provided in this study by CalEnviroScreen) is intended to support the two concepts of best practices recommended by Hernandez (2021): location and sustainability. Following guidance from Hernandez early in its development, the unit of interest in the initial framework report (Harvey et al., 2018) for calculation of the performance measures (i.e., the location) is the neighborhood rather than the individual or the region. The framework considers sustainability to include both social and environmental performance indicators, which matches best practices recommended by Hernandez (2021).

As discussed in the initial framework report, the interpretation of the social performance indicators is intended to identify final values for the indicators for the complete street project, and the amount of improvement or reduction in the indicator values. Access to the social determinants means access to opportunity (Hernandez, 2021), and transportation is the service that provides access to destinations that provide opportunity. The performance indicator calculation results are also intended to provide data for identification of investments in neighborhood transportation infrastructure in addition to complete streets that are needed to improve indicator values. In particular, investments in transit access and use of complete streets to connect transit to opportunity destinations in the neighborhood and in adjacent neighborhoods can improve many of the indicators.

Complete Street Design Guidelines and Policies

Several national, state, and local government complete street design guides were published in the last decade. Some examples of popular complete streets design guides include the National Association of City Transportation Officials (NACTO), North Carolina Department of Transportation (DOT), Florida DOT, New York City, Chicago, Boston, Philadelphia, City of Los Angeles and several others (Harvey et al., 2018). A list of complete streets policies and guides at different levels (i.e., state, regional, county, and city levels) was also published by the American Association of Retired Persons (AARP, 2019).

“The elements of a complete streets policy” developed by the National Complete Streets Coalition (NCSC) is a guidance document that identifies ten elements of a comprehensive complete street policy (SGA and NCSC, 2018). The guidance lists ten elements of an ideal complete street policy: (i) vision and intent, (ii) diverse users, (iii) commitment in all projects and phases, (iv) clear, accountable expectations, (v) jurisdiction, (vi) design, (vii) land use and context-sensitivity, (viii) performance measures, (ix) project selection criteria, and (x) implementation steps.

The guidance states that considering these elements leads communities to implement policies efficiently, balance different modes’ needs, and support economies, natural environments, and cultures. These elements are considered a best-practices national model that can be applied to all levels of governance in most types of CS policy (SGA and NCSC, 2018; SGA and NCSC, 2019).

The model developed in this report combining the use of social performance measures and socio-economic data regarding the neighborhood the complete street is intended to support provides an example of how socio-economic data can be integrated into the SLCA model using available tools. CalEnviroScreen data was used for these case studies since it appears to be a data source that is annually updated, contains a good array of data that provides indicators of local social and economic stability, and can be easily used because it has data for the case study corridors. The model addresses the following elements of the guidance: (ii) identification of the expected users and their social and economic conditions; (vii) performance measures including social performance measures. These two elements can be used to support (iv) clear, accountable expectations and (ix) project selection.

Performance Measures Considered in Complete Street Case Studies

More quantitative approaches are needed to evaluate the environmental, social and economic advantages and disadvantages of complete streets for cities and local authorities to select between alternative complete street designs, and to prioritize funding between alternative projects. To achieve these goals, performance measures and indicators are needed to support the decision-making process (Lenker et al., 2016).

In the last decades, many successful complete street projects in different states and cities of the U.S. have been performed (Gregg and Hess, 2019). Ranahan et al (2014) interviewed representatives from several municipalities with active complete street programs and found that none of them had gathered measurable data to calculate the impacts of their complete street projects. Ranahan et al.’s report provided a list of performance measures to demonstrate the impact of municipalities’ complete street initiatives. The indicators evaluated seven areas of impact in their study: bicycle/pedestrian, citizen feedback, economic, environmental, health, multi-modal level of service, and safety. The resources used in their study included agency reports, existing complete street policies, journal articles, and scholarly books identified through electronic database searches (including google scholar, academic search complete, masterFILE Premier, EBSCOhost, MEDLINE), and phone interviews. They used McCann and Rynne’s (2010) framework to classify and evaluate five complete street projects in terms of “outputs” and “outcomes”.

Outputs were defined as the main features to classify the complete street projects (e.g., number of crosswalk enhancements, miles of on-street bicycle routes, etc.). Outcomes of complete street projects (i.e., bicycle/pedestrian, citizen input, economic, environmental, health, multi-modal level of service, and safety) were defined in terms of the impacts experienced by citizens, businesses, and the environment. Ranahan et al (2014) in their study used a measurement tool for each category that was developed considering potential importance, frequency of use, availability, cost, and strategies for measurement.

Lenker et al (2016) evaluated the impacts of complete street projects in Buffalo, New York, and explored the feasibility of the data collection methods. Eight street corridors were selected due to their socio-economic diversity, a mix of commercial and residential uses, and a range of complete street features. The authors surveyed some residents, merchants, and streetscape users who lived near the complete streets or used them. Surveys covered completed and planned (future) complete street projects.

To obtain a diversity of impacts in their study, the following data collection tools were used, including (i) streetscape quality (functional and aesthetic items in pedestrian spaces that provide amenity and utility to pedestrians and other street users); (ii) street usability and satisfaction for drivers, bicyclists, and pedestrians; (iii) traffic volume for vehicles, pedestrians, and bicyclists; (iv) accidents and injuries; (v) economic vitality; and (vi) health impact. It was determined in the study that after the complete street was built, 73.5% of residents, 58.4% of merchants, and 75.7% of streetscape users presented that they were “much more satisfied” or “somewhat more satisfied” with the street (Lenker et al., 2016). Considering available pre-implemented and post-implemented data points, the study results revealed that complete street corridors were safer in terms of crashes and injuries and absorbed higher volumes of pedestrians, bicyclists, and vehicles than the conventional street before conversion (or planned conversion).

Sukumana et al (2019) emphasized the needs of bike lanes in conventional streets and analyzed the design of bicycle lanes based on the complete streets concept for a road segment in Indonesia with high demand for both vehicle and bicycle transportation. The authors used a non-experimental descriptive research approach along with qualitative and quantitative approaches for their study. Data collection consisted of nonrandom on-site participant interviews and questionnaires regarding bicycle user's perceptions of security concepts and comfort using a bicycle lane in a complete street concept. The answers to the survey results indicated a large preference for a 1.5 m bicycle lane in particular sub-segments of the roadway to provide safety based on vehicle traffic levels, with higher traffic segments having a higher preference for the bicycle lane.

Of these studies considering performance measures for complete street projects (Lenker et al., 2016; Gregg and Hess, 2019; Ranahan et al., 2014; Sukmana et al., 2019), none of them evaluated the socio-economic and environmental impacts of the projects using the LCA approach.

Environmental and Socio-Economic Life Cycle Assessment of Complete Streets

Life Cycle Assessment (LCA) is a tool to quantify the impacts of a product or system. Figure 1 shows a generic model of the life cycle stages for a product. This systematic approach identifies where the most relevant impacts occur and where the most significant improvements can be achieved while identifying potential trade-offs.

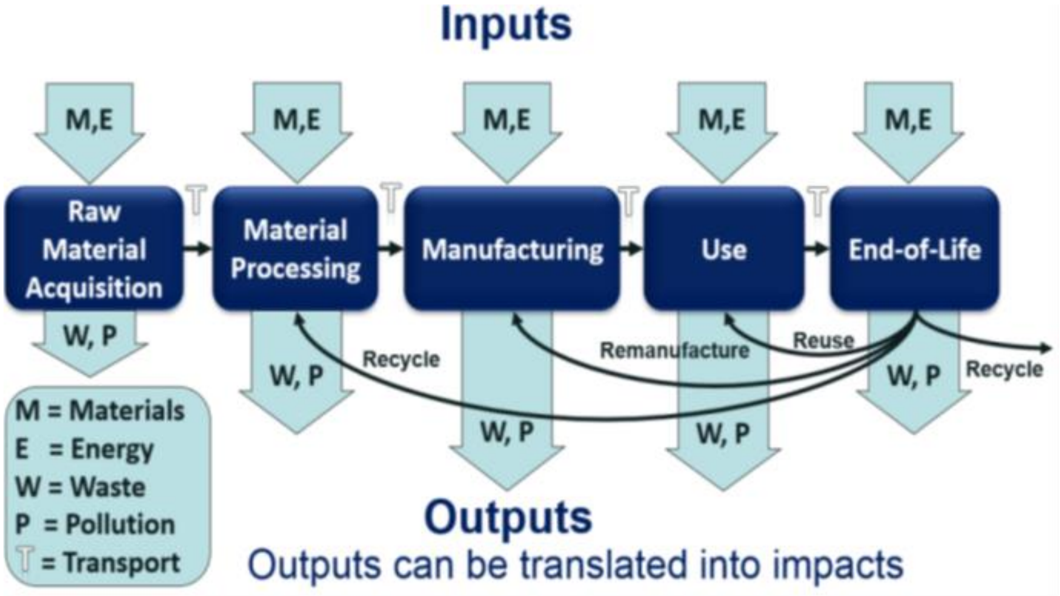

Figure 1. The General Life Cycle of a Production System (Kendall, 2012)

The general framework for using LCA studies as defined by ISO 14040 (2006) consists of four major phases: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation. LCA can be used for a variety of purposes, such as those identified by (Harvey et al., 2014):

- Identifying opportunities to improve the environmental performance of products at various points in their life cycles,
- Informing and guiding decision-makers in industry, government, and non-governmental organizations,
- Selecting relevant indicators of environmental performance from a system-wide perspective
- Quantifying the environmental performance of a product or system.

LCA is proposed by this series of studies and some work by others as an appropriate tool to quantify environmental and social impacts of urban streets. However, most of this work has focused on environmental impacts of materials (such as Gamez Garcia et al., 2019; Hoxha et al., 2021) without considering the use stage and rethinking approaches to environmental LCA of transportation projects in general (Saxe et al., 2021), as does the environmental part of the framework considered in this study (Saboori et al., 2020). No study on LCA for complete streets that considered the combined environmental effects of construction and maintenance and their effects on the use stage was found in the literature except the one that was performed by the authors in 2018 (Harvey et al., 2018).

A lack of socio-economic impact indicators and their corresponding quantification methods/models has been observed in LCA for some time (Rosenbaum 2014). Social life cycle assessment (SLCA) is still at the early stages of development (Haaster et al., 2017, Kuhnen and Hahn, 2017, Martinez-Blanco et al., 2015, and Benoit et al., 2010), unlike well-established methodologies such as environmental LCA (eLCA) and life cycle cost analysis (LCCA). UNEP and SETAC (Benoit et al., 2013) published “The Methodological Sheets for Subcategories in Social Life Cycle Assessment” to complement the SLCA Guidelines published in 2009 by the United Nations Environment Programme (UNEP) and support the development of SLCA case studies. The purpose of the UNEP sheets was to clarify the concepts of subcategories, recommended data sources, and existing policies for the SLCA (Benoit et al., 2013). The proposed framework by UNEP adopted the four LCA phases: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation. According to this framework, SLCA can be applied as a standalone tool or combined with LCA to complement LCA with social and socio-economic indicators (Benoit et al., 2013; Du et al., 2014). Although UNEP developed a framework guideline for SLCA (Benoit et al., 2013), there is still a need for a framework for SLCA to measure the social impacts during the supply chain and product life cycle due to a lack of general standardized indicators (Kuhnen and Hahn, 2017; Corona et al., 2017; Arcese et al., 2018; Kroeger and Weber, 2015).

Kuhnen and Hahn (2017) argued that there is a need to standardize social indicators that provide uniform rules to avoid unnecessary variation and incomparable assessments. Their review paper entitled “Indicators in Social Life Cycle Assessment, A Review of Frameworks, Theories, and Empirical Experience”, used five main guidelines, including Global Reporting Initiative (GRI) sustainability reporting guidelines, UNEP and SETAC SLCA guidelines and methodological sheets, UN millennium and sustainable development goals, Social Accountability International (SAI) SA 8000, and ISO 26000. Inconsistencies, gaps, and trends in SLCA research indicators across industry sectors were provided in these guidelines. In addition, the authors reviewed 141 scholarly articles that considered how to incorporate a life cycle or supply-chain perspective. Their reviews showed that the focus of most of the studies was on worker-related and health-related indicators which they argued missed other important indicators. They also found that many of the studies remain conceptual rather providing empirical data; 37% of the reviewed literature included non-empirical (conceptual) articles, and 63% empirical studies, including 50% qualitative and 50% quantitative approaches.

According to the UNEP guidelines (Andrews et al., 2009), the social life cycle impact assessment (SLCIA) phase includes three steps to define social and socio-economic impacts via social and socio-economic mechanisms as can be seen in Figure 2.

1. Selecting impact categories, characterization methods, and models.
2. Linking inventory data to specific SLCIA sub-categories and impact categories
3. Determining and calculating sub-category indicator results

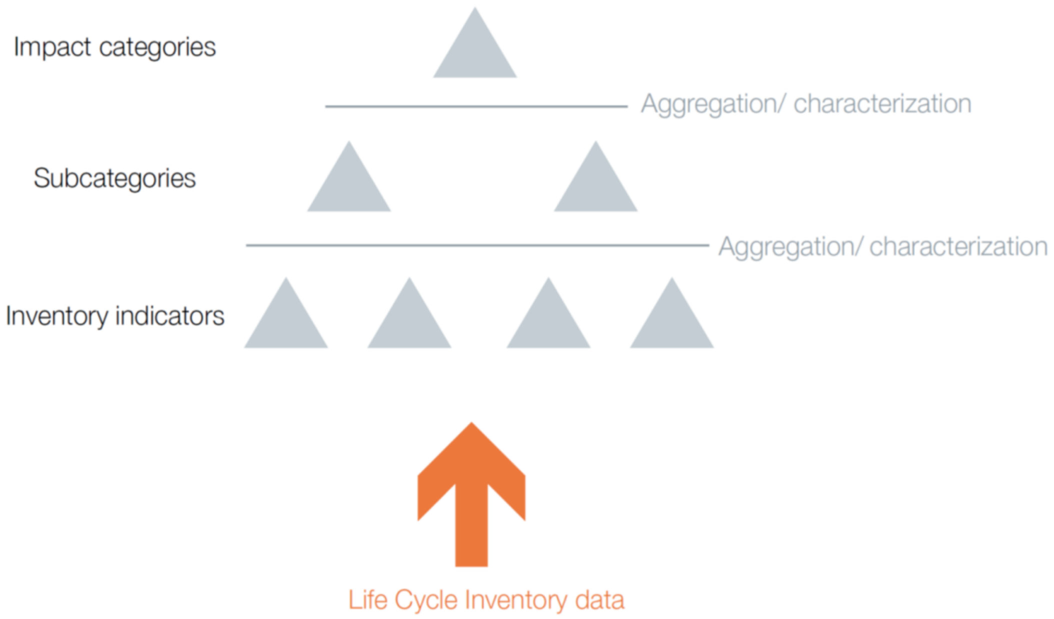

Figure 2. Concept of Subcategory (Andrews et al., 2009, Page 70)

According to the UNEP guidelines (Andrews et al., 2009, Benoit et al., 2013), two types of SLCIA methods or characterization methods are identified: Type 1) performance reference points, and Type 2) the causal-effect relations between indicators and social impacts. In Type 2 impact categories, as in eLCA, quantitative data and cause-effect chain modeling is required to aggregate indicators in characterization models. On the other hand, Type 1 impact categories do not make use of causal-effect chains. They use ordinal scales describing the risk, performance, degree of management or comparing the results to the context. The semi-quantitative form of Type 1 impact category models use weighting systems called performance reference points for aggregation.

Qualitative and semi-quantitative indicators such as surveys and interviews are usually used in SLCA because of the nature of social impacts. Data collection is one of the most challenging parts of SLCA (Andrews et al., 2009; Du et al., 2014; Benoit et al., 2013; Haaster, 2017; Corona, 2017). Because the evaluation of qualitative indicators is subjective, categorizing such indicators into a scale or scoring system helps to convert the data to a form suitable for quantitative analysis (Andrews et al., 2009).

Most of the work on SLCA to date has been looking at relatively large-scale systems, such as countries, companies, or commonly available products. There has not been much work on SLCA for projects at the typical scales of a complete streets project: the neighborhood scale where the project is built, and the network-scale for the network that the project contributes to. A framework to quantify environmental impacts using LCA for complete streets was developed in an earlier study (Harvey et al., 2018). That framework developed qualitative, quantitative and semi-quantitative indicators selected from a Federal Highway Administration (FHWA) guidebook for pedestrian and bicycle performance measures (Semler et al., 2016), and a

California Department of Transportation (Caltrans) set of performance measures (Caltrans, 2017a). That framework (Harvey et al., 2018) proposed that the neighborhood is the best scale for determining and interpreting SLCA impacts. Two other scales were not selected for calculation of indicators: the individual and the region. Transportation infrastructure investments such as complete streets affect space at the scale, and it is difficult if not impossible to apply the use of that space to individuals. At the same time, regions often contain distinct neighborhoods with different densities of destinations, different transit options, and different social and economic demographics. Complete streets are built at the scale of one or several neighborhoods and affect people at that scale in terms of transportation. Regions should also be considered when looking at inter-neighborhood connectivity.

Performance Indicators for Complete Streets

Two primary sources used to develop a list of potential performance indicators in the complete streets LCA framework considered in this study were the FHWA Guidebook for developing performance measures for pedestrian and bicycle travel (Semler et al., 2016) and a Caltrans technical report regarding the development of active transportation programs (Caltrans, 2017a). Table 1 shows the list of social performance measures that were included in the complete street LCA framework based on adaption of guidance from these two sources. The indicators and methods of calculation for the indicators are primarily taken or adapted from the FHWA Guidebook, except as noted in the table. Definitions and calculation methods for these indicators are described in detail in Chapter 4.

The set of indicators evaluated in this study is based on work done by FHWA and some recommendations from Caltrans that are more than 6 years old. There has been considerable work on level of service indicators for bicycle and pedestrian travel since then. While a complete update of the indicators was not part of the proposal for this project, a limited review of updates to the level of service indicators was completed.

A conference reviewing pedestrian and bicycle safety research conducted at university transportation centers was held in December 2016 and the proceedings were published by the Transportation Research Board (TRB, 2016). Results of breakout sessions at the conference regarding bicycle travel and infrastructure identified a need to bridge “the gap between perceptions of safety and actual safety outcomes”. The groups called for more effective quantification of the “performance of the infrastructure and using the correct surrogate safety measures that translate into meaningful safety outcomes and reductions in crashes and serious injuries.” This points out that BLOS is a measurement of perception of risk and safety, while the Crashes performance indicator is measurement of the most dangerous of safety outcomes.

A pedestrian and bicyclist road safety audit guide produced by Goughner et al (2020) for the Federal Highway Administration lists the factors influencing a pedestrian’s decision to walk or not as including (only those affected by the infrastructure shown):

- Distance and access to desired destinations

- Accessibility and space, where space includes conforming to Americans with Disabilities Act (ADA) specifications for dimensions
- Intersection safety
- Safety and comfort

Table 1. Social performance measures selected for use in the proposed complete streets LCA framework (Harvey et al., 2018)

Selected Category	**Selected Performance Measures**
Accessibility	Access to Community Destinations
	Access to school
Jobs	Access to Jobs
	Job Creation
Mobility/Connectivity	Active Transportation to Local and Regional Transit Connectivity Index*
	Connectivity Index
	Bike/Pedestrian Delay
	Level of Service (Auto)
Safety/Public Health	Level of Service (Bicycle Level of Service)
	Level of Service (Pedestrian level of Service)
	Level of Service (Bicycle Level of Stress)
	Crashes
	Physical Activity and Health
	Vehicle Miles Traveled (VMT) Impacts
	Pedestrian Miles Traveled (PMT)*
	Bicycle Miles Traveled (BMT)*
Livability	Green Land Consumption
	Street Trees

Note: * Not in the FHWA guidance

Regarding safety and comfort, the FHWA guide notes that factors affecting the pedestrian's perception of safety and comfort by the pedestrian "include high-speed traffic, lack of separation from vehicles, inadequate crossing facilities, lighting conditions, and poor quality of the walking experience."

Principles affecting a bicyclist's decision to use their bicycle identified in the FHWA guide, also limited here to those connected to infrastructure, include:

- Space, with specific dimensions recommended for the width of the bicycle lane or path

- Vertical gradients affecting ability to pedal, and accelerate and decelerate at intersections
- Network connectiveness, including directness of routes, and continuity and connectivity of bicycle facilities
- Comfort

Factors listed as affecting perceived bicycle risk and comfort “include degree of separation from vehicular traffic, lighting, roadway condition, and a rider’s confidence in ability.” The guide notes that other studies “found that bicyclists rated facilities having a higher degree of separation from drivers more positively, with protected/separated bike lanes and multi-use paths being the best. The study also showed that parking was a clear deterrent for comfort, perceived safety, and willingness to bicycle.”

A study by Mensomore et al (2020) found that “a key tool in designing low-stress networks is the use of separated or protected bicycle lanes, and intersections are the critical links.” The study was based on analysis of the perceived level of comfort of current and potential bicyclists from 277 survey respondents who rated 26 first-person video clips of a bicyclist riding through mixing zones, lateral shifts, bend-in, bend-out, and protected intersection designs. A total of 7,166 ratings were obtained from surveys conducted at urban and suburban location in four states. The results showed that designs that minimize interactions with motor vehicles, such as fully separated signal phases and protected intersections, are rated as most comfortable. Mean comfort drops off significantly for other designs and interactions with turning vehicles result in lower comfort ratings though there are differences for each design. Comfort decreases as the exposure distance increases, measured as the distance a person on a bicycle is exposed to traffic.

A review of bicycle level of service (BLOS) research over the last three decades completed in 2020 by Kazemzadeh et al., focused on user perceptions of comfort to provide guidance for decision-makers and planners. Separated bicycle facilities were noted to consistently rank as most important features. The review found that “despite general agreement among existing BLOS variables and the adopted indices, several important research gaps remain to be filled.” Those mentioned included attention to trip-end facilities such as bicycle parking facilities (also noted in the FHWA guide), the challenges associated with separated bicycle facilities (e.g., the presence of electric bikes and electric scooters)”. Other considerations covered regarding infrastructure included utilities in the path such as access covers, pavement macrotexture and roughness, and the presence of speed bumps use for vehicle traffic calming.

Fitch et al (2022) reported results from a similar study to Mensomore et al’s using video from a variety of urban and semi-rural roads around the San Francisco Bay Area where bicycling rates vary. The results indicated considerable effects of socio-demographics and attitudes on absolute video ratings, but relative universal agreement about which videos are most comfortable and uncomfortable. The presence of bike infrastructure and low speed roads are especially important in generating higher comfort ratings, but may still not convince everyone to use a bicycle. The results provide guidance for improving roads with on-street bike facilities where protected or separated facilities may not be suitable.

This framework and these performance measures are tested in three case studies in this current study by quantifying the socio-economic and environmental impacts of complete streets and then comparing them with conventional streets. Applying the framework to different case studies helped to evaluate the proposed performance measures' usefulness, relevancy, and feasibility and to identify changes and modifications to improve the original framework.

Summary

A review of existing literature suggests that complete streets are designed with the goal of achieving both social and environmental benefits. However, complete street assessments often lack a rigorous quantitative analysis of potential benefits of both types in practice.

Most of the work found in an updated review of the literature has focused on environmental impacts of materials without considering the use stage. There is work rethinking approaches to environmental LCA of transportation projects in general. No study on LCA for complete streets that considered the combined effects of their construction and maintenance and their effects on the use stage was found in the literature except the one that was that was presented in the framework work report prior the study presented in this report (Harvey et al., 2018).

Although LCA may be an appropriate tool to quantify environmental and social impacts, there is a lack of socio-economic impact indicators in LCA for transportation projects at the project level and at the neighborhood scale. An extensive literature search was conducted to screen and select the best indicators that consider clarity, data availability, relevance (whether they reflect the goals of the complete street approach), applicability, overlap, and simplicity of calculation or estimation.

The application of the LCA framework to complete streets in the Harvey study was influenced by the SLCA framework presented in the UNEP studies (Andrews et al., 2009; Benoit et al., 2013). The UNEP studies introduced five important indicators for social well-being that were incorporated into the Harvey study as performance measures suitable for inclusion in an SLCA model for complete streets assessment: Accessibility, Jobs, Connectivity/mobility, Safety/public health, and Livability. Finally, a key point in the Harvey study is its focus on the neighborhood as an important unit of analysis since it is at the neighborhood scale where complete streets create impact and where social and economic benefits can be measured.

Chapter 3: Overview of Complete Street LCA Case Studies

Goal and Scope

The goal of this study is to test and demonstrate the complete street LCA framework developed in the previous study by performing three case studies. The case studies have been solicited in different parts of California and in more and less advantaged neighborhoods to evaluate results from the framework for both types of neighborhoods. The case studies include projects in urban/suburban areas and a suburban/rural area.

The case studies considered are:

- Urban: San Fernando Street complete street project located in an advantaged neighborhood of San Jose, CA
    - Complete street length: 1.3 miles
    - Type of street: mixed-use commercial and downtown two-way
- Suburban: Franklin Boulevard complete street project located in a disadvantaged neighborhood of Sacramento, CA
    - Complete street length: 1.6 miles
    - Type of street: four-lane arterial
- Suburban/Rural: Kentucky Avenue complete street project located in Woodland, CA
    - Complete street length: 1 mile
    - Type of street: mixed-use corridor

The evaluation of the San Fernando Street and Kentucky Avenue complete street projects, which were already built at the time of evaluation, is based on performance before and after the project's completion. In contrast, the Franklin Boulevard complete street project assessment, which had not yet been constructed, is based on proposed designs.

The system boundary for this study considers the impacts of changes in each of the case studies before and after constructing the complete street projects, considering the entire neighborhood and also the project within the larger active transportation road network. The functional unit for the environmental LCA is the complete street project itself. The functional unit for the SLCA is defined for each performance measure separately, and the data are then collected for each performance measure. The case studies details are provided in the following section of this chapter. The following chapter presents quantification of socio-economic indicators, followed a chapter presenting the quantification of the environmental impacts using the socio-economic and environmental LCA framework.

Urban: San Fernando Street, San Jose, CA

San Fernando Street, located in downtown San Jose, is a mixed-use commercial street that connects San Jose State University to the Diridon Caltrain station (mainly in district 3). This two-lane street includes class II bike lanes[2] and parallel parking lanes. The existence of multiple restaurants, bars, and residential buildings in San Fernando Street provides opportunities for active transportation to support urban street life. Santa Clara Street is one of the most important streets parallel to San Fernando Street. When Bay Area Rapid Transit (BART) construction on Santa Clara Street redirected auto traffic, bike, and pedestrian activities to adjacent streets, the function and identity of San Fernando Street changed considerably. This change lead to San Fernando Street becoming the east-west spine of downtown San Jose. Therefore, San Fernando Street as a main pedestrian and bicycle route that connects Caltrain to downtown San Jose needed an appealing, clear, and strong path. Figure 3 shows the San Fernando Street land-use zoning map a) in 2020 and b) in 2040, based on the general plan of San Jose (City of San Jose, 2020a; City of San Jose, 2018). Table 2 shows the surrounding land use zones of San Fernando Street This street is surrounded by a mix of commercial and residential neighborhoods in addition to downtown San Jose and San Jose State University.

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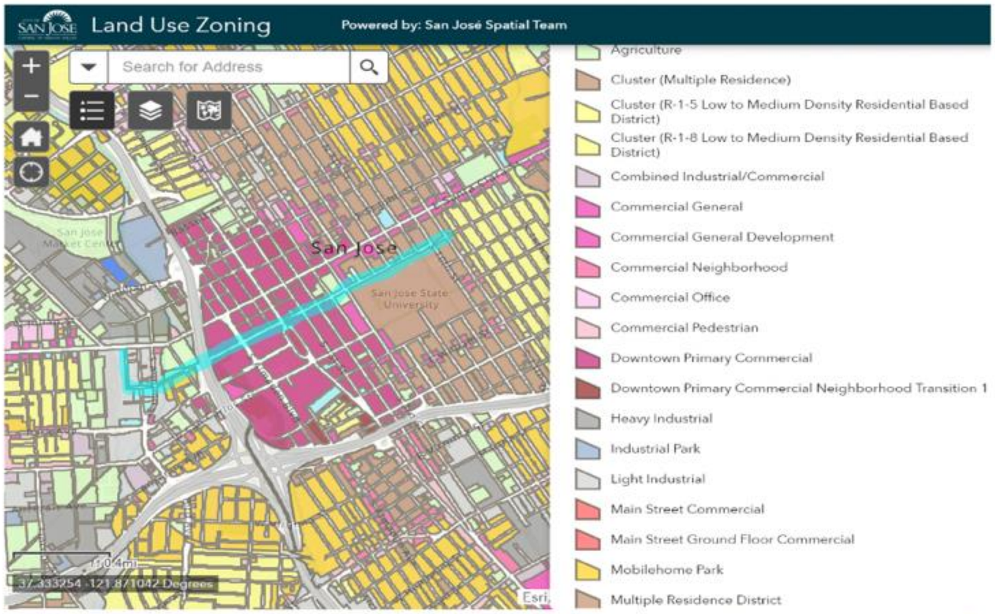
[2] Bike lanes that are defined by pavement striping and signage on a portion of a roadway along streets.



a) San Fernando Street land-use zoning map in 2020, based on the general plan (project location highlighted in light blue)

b) San Fernando Street land-use zoning map in 2040, based on the general plan (project location highlighted in light blue)

Figure 3. San Fernando Street land-use zoning map before (a) and after (b) the construction of complete street (City of San Jose, 2020a)

Table 2. Current Land Use Zones in the surroundings of the San Fernando Street

San Fernando Street	Destinations on the right of the street	Destinations on the left of the street
Between 10th-9th Street	Offices	Offices
Between 9th-8th Street	Residential	Offices
Between 8th-7th	Offices- stores	Offices- stores
Between 7th-6th Street	Offices- stores	Offices- stores
Between 6th-5th Street	Offices- stores	Offices- stores
Between 5th-4th Street	Offices- stores	Offices- stores
Between 4th-3rd Street	Offices- stores	Offices- stores
Between 3rd-2nd Street	Offices- stores	Offices- stores
Between 2nd-1st Street	Offices- stores	Park
Between 1st-Lightson Street	Offices- stores	Offices
Between Lightson Street- Market Street	Offices- stores	Offices
Between Market Street -San Pedro Street	Offices- stores	Offices
Between San Pedro Street -Almaden	Offices- stores	Offices- stores
Between Almaden Avenue- Almaden	Offices- stores	Offices- stores
Between Almaden Boulevard- Guadalupe	Park-Offices	Offices- Stores-Parks
Between Guadalupe Pkwy-Delmas	Parks	Parks- Residential
Between Delmas Avenue-Gifford Avenue	Parks	Residential
Between Gifford Avenue- Autumn Street	Parks	Residential- Parks
Between Autumn Street - Montgomery	Parks	Parks
Between Montgomery Street - Diridon	Parks	Not applicable

Two complete street projects have been implemented on San Fernando Street during the last ten years. The first project was funded by the Metropolitan Transportation Commission (MTC) in 2010 and is entitled “San Fernando Street enhanced bikeway and pedestrian access”, with the goal of “encouraging pedestrian and bicycle mobility by providing accessible, safe, and comfortable connections between transit, businesses, housing and recreation, and enhancing downtown environment and experience for workers, visitors, students, and residents” (MTC, 2020a). This project improved the existing bicycle and pedestrian facilities of San Fernando Street between Cahill Street and 10th Street. The scope of the project was to install an enhanced colored bike lane with a buffer zone on both sides of the street, install energy-efficient lighting, street trees, sidewalks, curb gutter, signage, pavement markings, and striping; to enhance all existing crosswalks; to upgrade wheelchair ramps to American disability act (ADA) compliance; and to improve drainage, traffic signal, and bulb-outs.

The performance of the street was expected to be improved by this project as follows:

I. facilitate a safe and convenient walking and bicycling experience to and from the public transit facilities to enhance pedestrian and bicycle accessibility,

II. provide a direct route for pedestrians and bicycles to the Diridon Station, as the main transit hub in the city of San Jose for BART, High-Speed Rail, and Caltrain.
III. provide a direct connection between San Jose State University and the Diridon Station in addition to connections to the downtown business district, housing, and recreational facilities along the San Fernando Street

The second project was funded by MTC in 2018 entitled "Better Bikeway San Jose- San Fernando Corridor". The scope of this was an investment in the San Fernando Street corridor's traffic and bicycle signals, transit boarding islands, and construction of Dutch-style protected intersections. The focus of this project is to improve and build class II [3]and class IV [4]bike lanes, bicycle parkings, sidewalks, lighting, ADA compliant ramps, traffic signal push buttons, pedestrian countdown signals, widening curb lanes, installing transit vehicle stops, directional signages, improving intersections, mid-block crossings, ADA facilities, and installing traffic signals responsive to bicycles and right turn only lanes (San Jose Downtown Association, 2016; MTC, 2020b) compares the elements of the complete street considered in this case study. Figure 4 shows the intersection on San Fernando Street and 10th Street before and after constructing the second complete street project in 2018.

a) Before the complete street implementation (Google Map, 2016)

b) After adding the complete street features (Google Earth, 2020)

Figure 4. The intersection of San Fernando Street and 10th Street, before (a) and after (b) the construction of the complete street project

The San Fernando complete street project is part of the city of San Jose's better bike plan network. The left side of Figure 5 shows the 197 miles bikeway put into service between 1970 and 2009. The right side of Figure 5 , which illustrates the bikeway before the San Jose city

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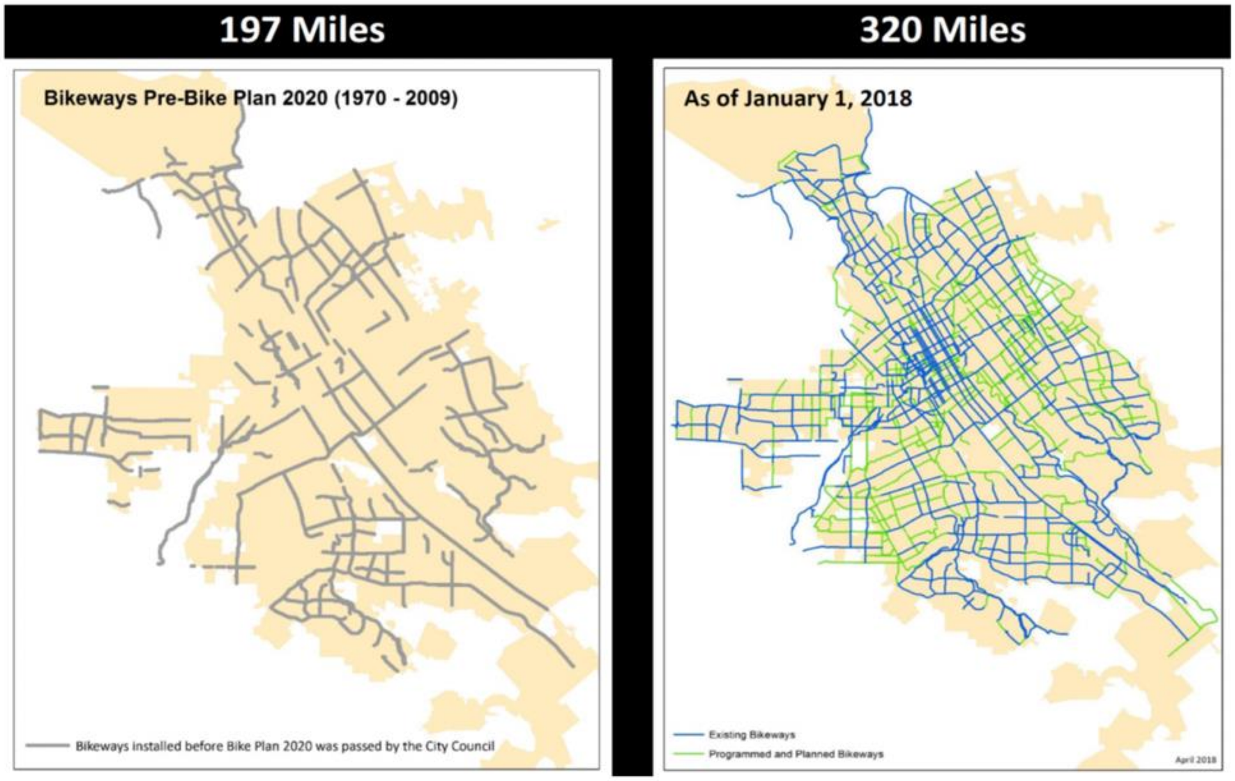
[3] "Class II bikeways are bike lanes established along streets and are defined by pavement striping and signage to delineate a portion of a roadway for bicycle travel. Bike lanes are one-way facilities, typically striped adjacent to motor traffic travelling in the same direction. Contraflow bike lanes can be provided on one-way streets for bicyclists travelling in the opposite direction" (Caltrans, 2017b).

[4] "Class III bikeways, or bike routes, designate a preferred route for bicyclists on streets shared with motor traffic not served by dedicated bikeways to provide continuity to the bikeway network. Bike routes are generally not appropriate for roadways with higher motor traffic speeds or volumes. Bike routes are established by placing bike route signs and optional shared roadway markings (sharrow) along roadways" (Caltrans, 2017b).

council had passed the bike plan 2020 (pre-planned), and in 2018 (during the implementation of the 2020 bike plan).



a. *San Jose Bikeway maps showing routes added to 2009 and completed (as of 2018*

b. *San Jose Bikeway maps showing planned following the San Jose Bike Plan 2020 (City of San Jose, 2020a)*

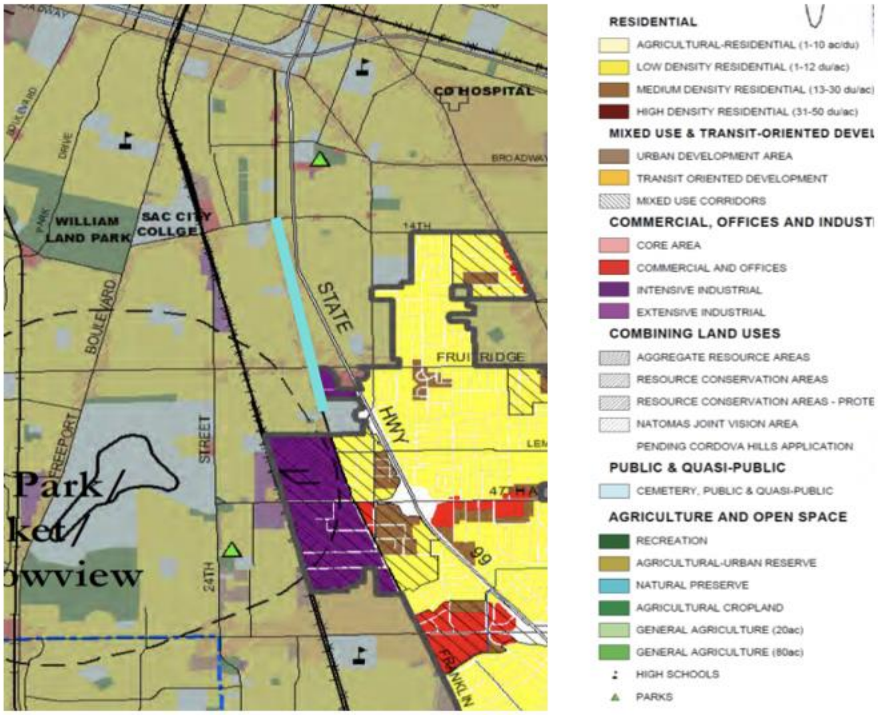
Figure 5. San Jose Bikeway maps showing (a) routes added to 2009 and completed (as of 2018) and (b) planned following the San Jose Bike Plan 2020 (City of San Jose, 2020a)

According to the San Jose better bike plan (adopted in 2009) and the San Jose 2040 general plan (City of San Jose, 2018) a network of separated bike lanes and protected intersections is to be installed throughout the downtown of San Jose through the Better Bikeways projects in 2018 and 2019, including the San Fernando complete street project. The build-out of the bicycle network is to eventually include 320 miles of routes.

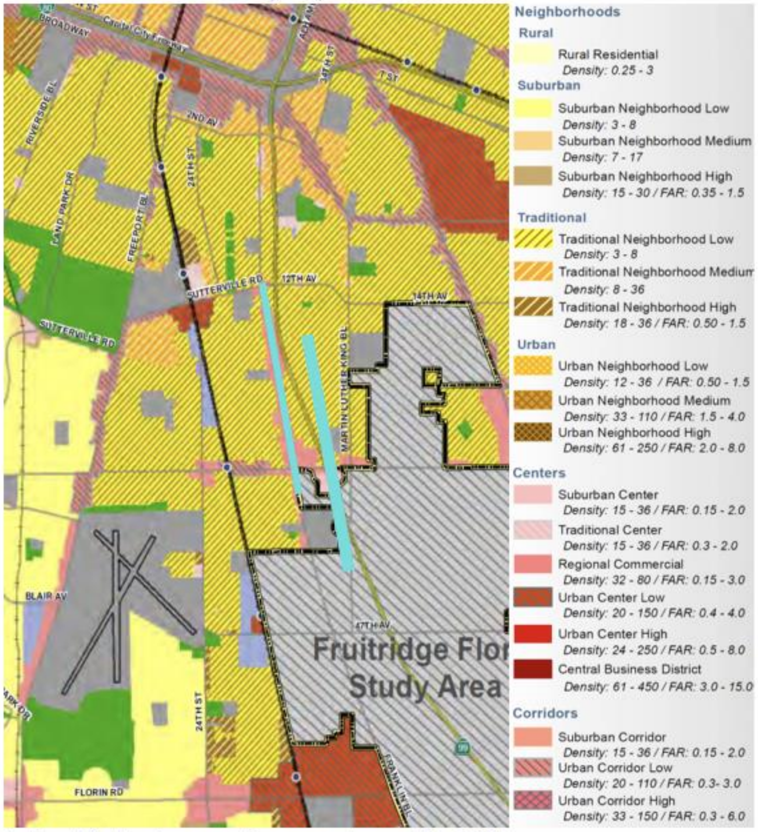
Suburban: Franklin Boulevard, Sacramento, CA

The Franklin Boulevard corridor is currently a four-lane arterial with limited pedestrian and bicycle amenities. It does not have bike lanes, ADA accessible sidewalks, and it currently supports high levels of truck traffic. This boulevard is in an economically disadvantaged area that needs investment and economic revitalization. In 2018, the City of Sacramento proposed a master plan for the development of the Franklin Boulevard to convert it to a complete street (City of Sacramento and Department of Public Works, 2018). The purpose of this complete street project, which is located between Sutterville Road (12th Avenue) and 38th Avenue, is to improve pedestrian and bicycle mobility, increase safety, provide access to businesses, and enhance connectivity for all users through improved roadways and streetscape designs.

Figure 6 shows maps from the general plan for Franklin Boulevard land-use zoning map a) in 2020 and b) planned by 2035. As can be seen in the figure, Franklin Boulevard between 12th Avenue and 38th Avenue includes commercial and residential neighborhoods.



a. *Franklin land-use zoning map in 2020*



b. Franklin land-use zoning map planned for 2035

Figure 6. Franklin Boulevard land-use zoning map before (a) and after (b) the construction of complete street, based on the Sacramento County General Plan (Sacramento County, 2020)

The proposed complete street will remove two travel lanes and substitute them with Class IV bike lanes[5] and accessible sidewalks. This project, which is located in the historic Monterey Trail district, is planned to transform the corridor into a welcoming and attractive gateway to the district, and adjacent neighborhoods. The Franklin Boulevard complete street project aims to create a pleasant destination for living and working via improving sidewalks, and enhancing buffered bicycle lanes, marked pedestrian crossings, and lighting. This project is funded by the Sacramento Area Council of Governments (SACOG) Community Design Grant and local funds through preliminary engineering, which includes environmental, public outreach, and conceptual design (City of Sacramento, 2020a; MIG, 2019). Figure 7 shows the current view of Franklin Boulevard and the expected view after the proposed complete street project on this Boulevard is completed.

a) Franklin Blvd, before transforming to a complete street (currently) (Google map, 2020)

b) Franklin Boulevard, prposed view after implementing the proposed complete street project (MIG, 2019)

Figure 7. Current (a) and expected (b) views of Franklin Boulevard

Figure 8 shows the existing bike facilities as well as the proposed bicycle facilities for this project. According to the Sacramento County Bike Master Plan, a network of different classes of existing and proposed bicycle facilities is planned in which the Franklin Boulevard complete street project is included (City of Sacramento and Department of Public WorksCity of Sacramento Bicycle Master Plan, 2016)).

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[5] Bikeways/lanes or cycle tracks that are separated from other modes usually by vertical separators.

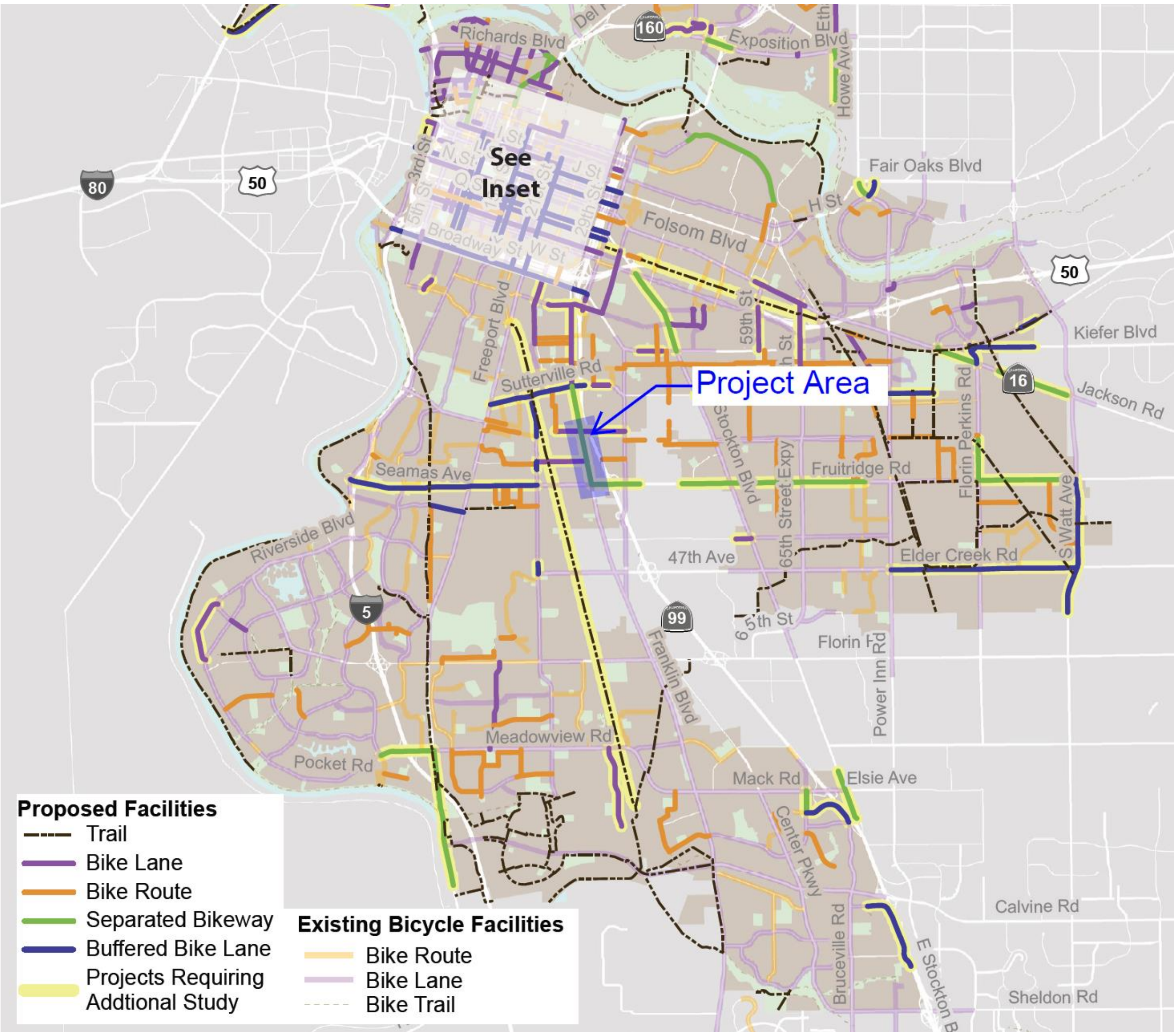
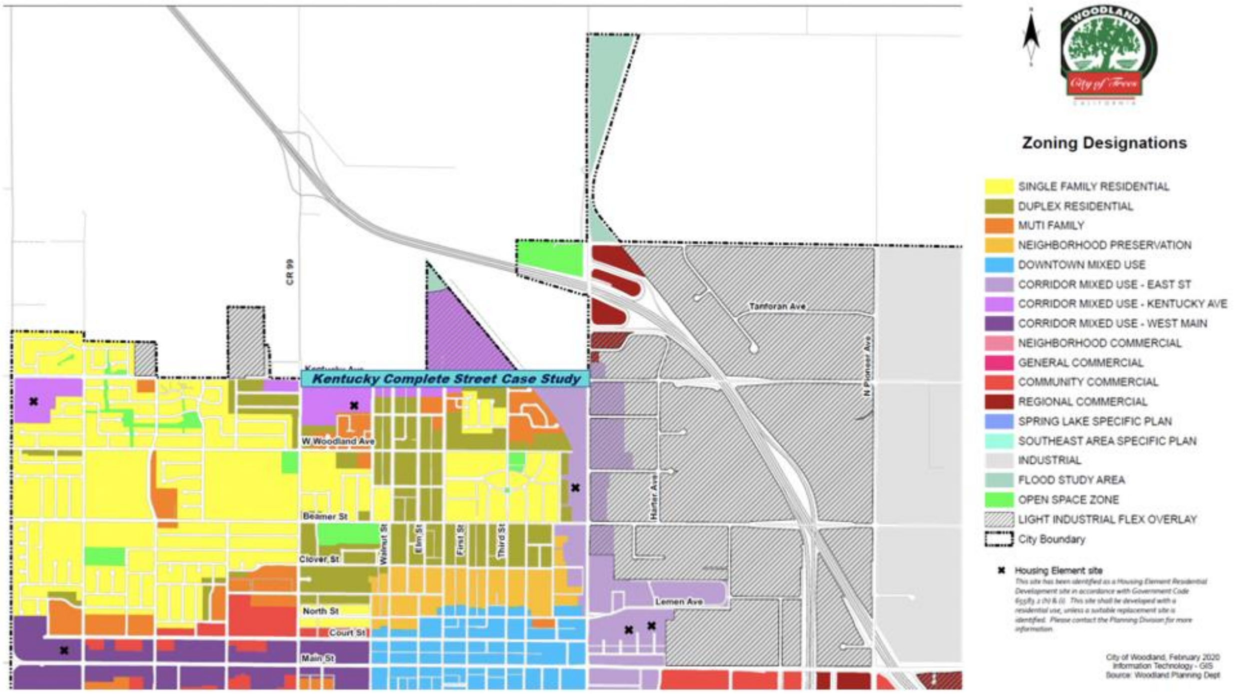


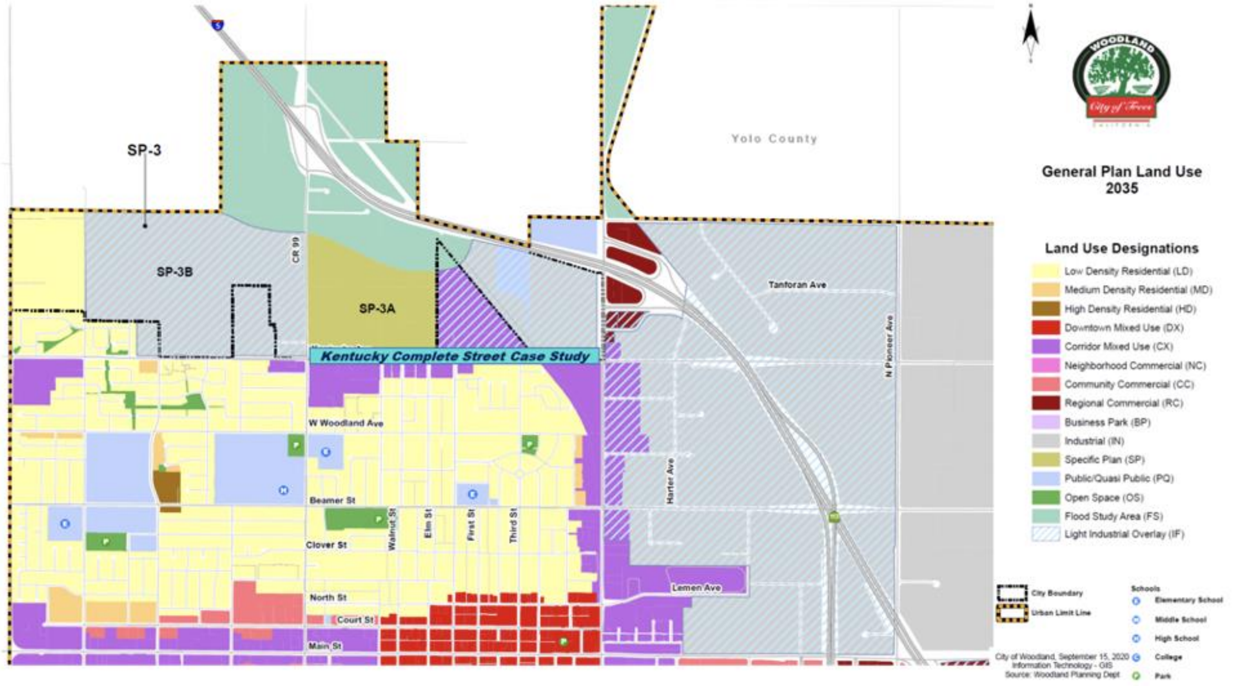
Figure 8. A network of different classes of existing and proposed bicycle facilities (City of Sacramento and Department of Public Works, 2018)

Suburban/Rural: Kentucky Avenue, Woodland, CA

Kentucky Avenue is a mixed-use corridor located in the northern part of the City of Woodland. As part of the complete street project, Kentucky Avenue was recently widened from 2 to 4 lanes from East Street to College Street and the roadway from East Street to West Street was reconstructed. The avenue previously had incomplete sidewalks and no bicycle lanes. The complete street project includes a major redesign including new landscaped-separated sidewalks, new bicycle lanes, drainage improvements, landscape medians, a new traffic signal at College Street, and modifications to signals at West Street and East Street. Figure 9 shows a map from the general plan of the Kentucky Avenue land-use zoning a) in 2020 and b) planned for 2035. This segment of Kentucky Avenue does not appear to be part of the planned network of bicycle routes in the 2002 Bicycle Transportation Master Plan (it does not appear in the list of planned routes, and the maps are difficult to read, [Woodland, 2002]).



a) Kentucky Avenue land-use zoning map in 2020, based on the general plan

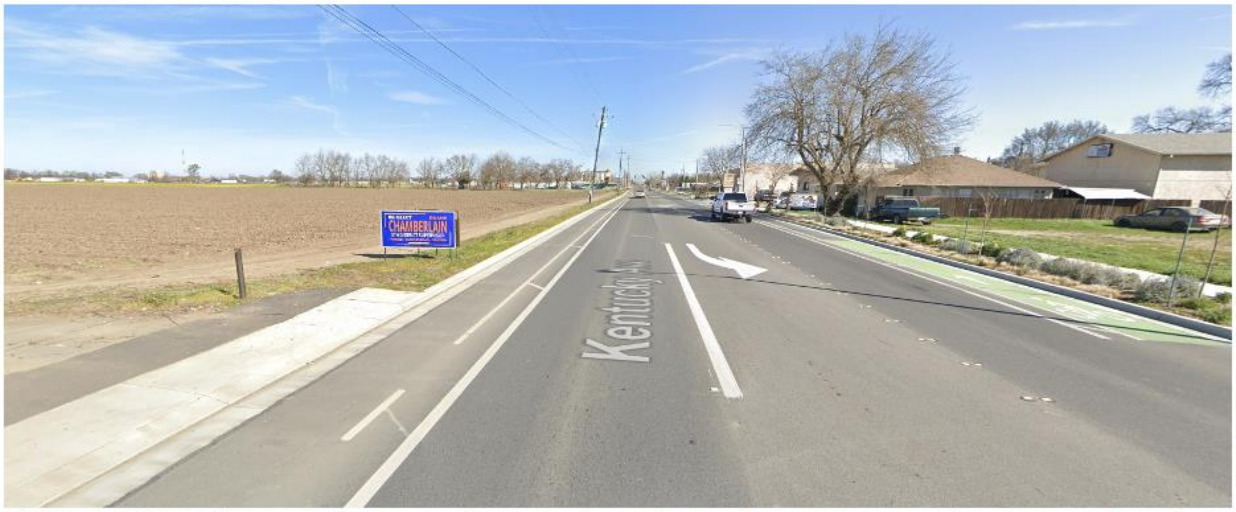


b) Kentucky Avenue land-use zoning map in 2035, based on the general plan

Figure 9. Kentucky Avenue land-use zoning map before (a) and after (b) the construction of complete street (City of Woodland, 2021)

Figure 10 shows the existing Kentucky Avenue (a) from 2017 Google Maps™ and the newly built complete street (b) from 2020 Google Maps™ that has been updated with dedicated bike lanes and sidewalks.

a) Before the complete street implementation (Google Map, 2017)



b) After adding the complete street features (Google Earth, 2020, Avenue has been updated with dedicated bike lanes and sidewalks)

Figure 10. The existing Kentucky Avenue (a) and newly built Kentucky Avenue complete street (b) (Before and after the construction of the Kentucky Avenue complete street project)

Chapter 4: Social Life Cycle Assessment (SLCA)

This chapter evaluates the socio-economic indicators in the LCA framework developed for complete streets by Harvey et al (2018) that quantify complete streets' socio-economic impacts before and after being built using the three case studies. The social and socio-economic impacts that have been evaluated in the case studies include access to community destinations, access to school, access to jobs, job creation, connectivity index, active transportation to local and regional transit connectivity index, pedestrian and bicyclists' delays, level of service, crashes, pedestrian and bike miles traveled, and street trees. The considerations regarding interpretation of indicator values for more and less advantaged neighborhoods and comparison of values between projects in different neighborhoods is also discussed in each performance measure section separately. Where applicable, a complete street that has not yet been constructed or completed has been evaluated using the design documents of that street.

A socio-economic base map derived from the California Communities Environmental Health Screening (CalEnviroScreen) tool has also been used to evaluate the case studies (OEHHA, 2020) and is discussed in detail later. CalEnviroScreen was used as an example of combining the use of the indicators with the use of a tool to evaluate the vulnerability and existing health, social, and environmental burdens of a neighborhood. This tool helps to identify the California communities, especially vulnerable ones most affected by several sources of pollution. CalEnviroScreen tool uses environmental, health, and socio-economic information to produce comparison scores for every census tract tied to census data for California. An area with the highest score experiences the highest socio-economic and environmental pollution burden. Color coding is also provided in these maps, along with the scores.

The next section of this chapter presents a summary description of the indicators, followed by assessments for each case study.

Performance Measures Description and Methodology

Access to Community Destinations

Access to community destinations reflects the proximity of pedestrian, bicycle, and transit infrastructure and services to origins and destinations. Community destinations include (Harvey et al., 2018; adapted from Semler et al., 2016):

- Parks
- Grocery stores
- Medical centers
- Senior day care centers
- Businesses with a certain number of employees
- High-density residential locations
- Community centers
- Community colleges
- Community services
- Government offices

- Major tourist destinations
- Major retail and entertainment locations
- Office buildings
- Places of worship
- Public libraries
- Retirement homes
- Transit centers
- Universities and colleges.

Transportation agencies should define specific destinations which are to be included in the scope of the case study analysis. It is important to mention that access to school is treated as a special separate performance measure which will be discussed in a later section of this chapter.

The assessment consists of counting the community destinations within a reasonable travel time or distance (active transportation or combination of active and transit transportation) of a complete street project. The density of community destinations in a neighborhood should be considered when interpreting the results from this indicator for a given neighborhood and comparing projects in different neighborhoods . This indicator should not be used to compare projects unless they have a similar number of destinations within some pre-determined range. Comparison of neighborhoods that do not have similar numbers of community destinations (potentially broken down by types) within a reasonable travel time or distance may be more of an indication that a community needs more community destinations than an indicator of the value of the complete street project to connect to destinations. Use of this indicator to prioritize funding for complete streets without this consideration will lead to the selection of projects in areas that are already advantaged in terms of the richness of destinations. If the preliminary analysis indicates that there are few community destinations, this will indicate that investment to increase the number of destinations would be the first step towards improving more equality of quality of life between the neighborhoods, and complete streets and transit can be included in those destination development projects to provide active transportation access (Harvey et al.,2018).

The required data for this performance measure is the number of destinations (depending on the category) and the number of people (employees/customers) who typically visit that destination, sorted by proximity to the complete street. Three values were calculated for this indicator: the access to community destinations before the construction (or proposed construction) of the complete street, the access to community destinations after the complete street, and the change in access to community destinations by means of the complete street. For this and the other two case studies, there was no access by complete street prior to the case study complete street, therefore the starting point for the change in access by means of the complete streets is zero access. The access values before and after are controlled by the number of destinations, which may go up or down for any number of reasons in the short time between before and after complete street construction.

The cumulative method was selected as a measurement method. Accessibility was calculated for specific time thresholds, and the result was a simple count of reachable destinations within each threshold.

$$A_i = \Sigma\ O_i\ f\,(C_{ij})$$

A_i = accessibility for location i
O_j = number of opportunities at location j
C_{ij}= time cost of travel from I to j
$f\,(C_{ij})$ = weighting function

$$f\,(C_{ij}) = \begin{cases} 1 & \text{if } C_{ij} \leq t \\ 0 & \text{if } C_{ij} > t \end{cases}$$

t = travel time threshold

Assumptions include:

- O: Number of students + employees,
- t= 20 min,
- f (C)= 1

According to the complete street LCA framework (Harvey et al.,2018) and FHWA guidelines (Semler et al., 2016), the following measures were proposed for evaluating access to community destinations. Operational measures of walking and cycling accessibility were reviewed to select the best method for each case study, or active transportation plus transit. Four situations were considered (see Figure 14) that include:

- Walking mode: A number of destinations can be accessed within half a mile along with a walking network from a given point on the network.
  - Three points on the complete street were selected that include two edge points and one point at the center of the street. A 0.5-mile radius circle is then drawn from each of the three points.
- Bicycling mode: A number of destinations can be accessed within two miles along with a bicycling network from a given point on the network.
  - Three points on the complete street were selected, which include two edge points and one point at the center of the street. A 2-mile radius circle is then drawn from each of the three points.
- Transit mode: A number of destinations can be accessed within three miles or 4.5-miles along with a transit network from a given point on the network.
  - Three points on the complete street were selected, which include two edge points and one point at the center of the street. A 3-mile and a 4.5-mile radius circle are then drawn from each of the three points.

For multimodal trips, transit schedules were studied for local buses, trains, and light rail. To calculate the average speed and travel times, the destination routes were mapped in Google Maps™ for different modes of transportation in a specific trip, which resulted in a multi-modal trip distance. Data collection is challenging for access to community destination performance measures since data needed (i.e., number of destinations in a specific area, number of employees, and number of customers) for this indicator's measurement were not collected by the cities from before or after construction (or design plans if not yet built). Therefore, historical satellite imagery of Google Earth™ was used for the data collection.

Access to Schools

Description and Methodologies

Access to school reflects the proximity of pedestrian, bicycle, and transit infrastructure and services to schools. Schools are separated from the access to community destinations indicator because of the vulnerability of the student population and the importance of helping to establish transportation mode choice impressions early in life for the full range of possibilities to be considered "acceptable" later in life (Harvey et al., 2018; Evenson et al., 2010).

The assessment should consider whether a school is accessible to the populations of students that are assigned to it if the complete street project is built and if the complete street project is part of a plan for an active transportation/transit network. If there are not enough schools, this would suggest that investment in neighborhood schools closer to student residences should be a first step towards more improving the density of school access between neighborhoods, and complete streets and transit can be included in those destination development projects to provide active transportation access. Having nearby schools is more important for disadvantaged neighborhoods because they tend to have fewer transportation alternatives to begin with (Harvey et al.,2018).

The assessment should also look at the change in the number of students who can access the school with the building of the complete street/transit project. As with the other access indicators, three values were calculated for this indicator: the access to schools before the construction (or proposed construction) of the complete street, the access to schools after the complete street, and the change in access to schools by means of the complete street. Use of the change in the number of students who have access by complete street is provided instead of only counting the number of students who have access since more advantaged neighborhoods may already have existing complete streets (Harvey et al.,2018).

According to the complete street LCA framework (Harvey et al.,2018), and FHWA guideline (Semler et al., 2016), the following measures are used for evaluating access to school.

- Number of schools can be accessed within a ½ mile along with a <u>walking</u> network functional for students from a given point on the network.
- Number of schools within 2 miles along with a <u>bicycling</u> network from a given point on the network.

- Number of schools within combined bike or walk and transit trip of 20 minutes to specific schools (Semler et al., 2016; Harvey et al., 2018).

Another suggestion for an additional measure of this indicator was to send a survey/questionnaire to school principals near the complete street to provide better information regarding students' and employees' travel behaviors to and from their school. As shown in Figure 11 , there is a possibility that students who live further away from the complete street do not necessarily need to use the complete street in their travel to school. Possible reasons include:

- Example A – The student may not be using the complete street as both the school and student's home are located on one side of the complete street.
- Example B – The student may only be crossing the complete street and may not be using it if both the school and student's home are not located on the same side of the complete street.

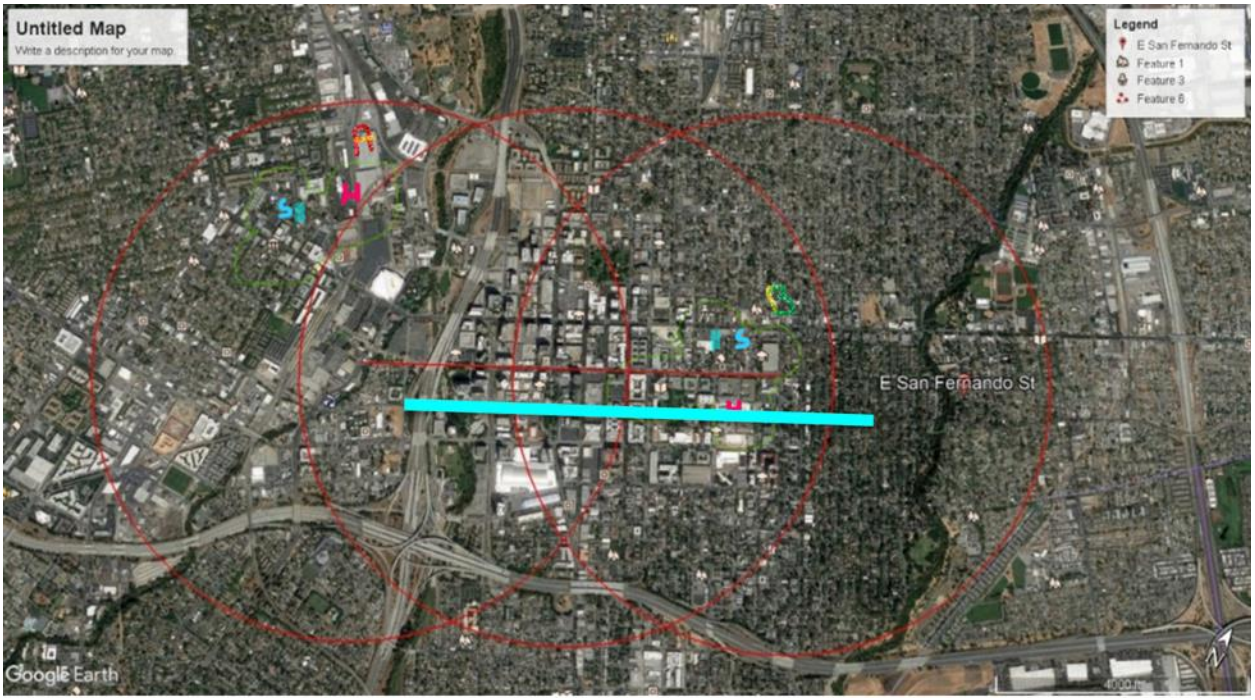


Figure 11. Possible Students' and Schools' locations

Questionnaire

Data for this indicator are hard to find. The research team decided to develop surveys for school principals who could provide better information about how students travel to the school, and students' and parents' perceptions. The survey instruments for elementary, middle, and high schools are provided in Appendix C. The survey/questionnaire was designed to aid the understanding about how children get to school and parent perceptions of safety and convenience including transit services and active transportation now available or that may be available after the construction of the complete street. Two of the major interests of the research team were to:

- Estimate the mode choice between student's homes and schools, and
- Learn effects of complete streets on student travel to and from school.

The aim of the surveys was quantification of the benefits to students from the conversion of streets into complete streets. No personal data of schools, school representatives, parents or students were collected. Participation in research was completely voluntary. The survey instrument and methodology were submitted and approved by the UC Davis Independent Review Board (IRB) for research involving human subjects.

Access to Jobs

Access to jobs illustrates the ability of pedestrian, bicycle, and transit infrastructure and services to provide access to places of employment. Transportation investment can impact communities since it offers people accessibility to a greater number and a greater variety of employment opportunities (Harvey et al., 2018 and Semler et al., 2016).

Access to jobs is particularly important for disadvantaged neighborhoods with low car ownership or the ability to pay for car use. Access to jobs is calculated by counting places of employment and estimating the number of jobs at each employment location. Places of employment are identified by sources such as Google Maps and Apple Maps. The evaluation identifies the number of places of employment within 20 minutes of a complete street/transit project. Comparison of projects in different neighborhoods should consider whether a similar number of places of employment exist within the pre-determined range. As with the other access indicators, three values were calculated for this indicator: the access to jobs before the construction (or proposed construction) of the complete street, the access to jobs after the complete street, and the change in access to jobs by means of the complete street. If there was no complete street access before the case study complete street project, then the initial value for change of access by a complete street was zero.

If there are few job locations within a neighborhood, then the indicator may suggest that private and public investment is needed to increase the number of places of employment in the neighborhood and include in that investment projects to provide active transportation/transit access. Interpretation of this indicator should also look at the change in the number of jobs that become accessible by complete street with the building of the complete street/transit project and the complete street network it is a part of, rather than the number of jobs that become accessible. Comparisons of the change of accessibility within the neighborhood for different projects can potentially provide a more useful result instead of the number of jobs made accessible (Harvey et al.,2018). As with the other access indicators, the number of jobs may increase, decrease or remain static over the short period between before and after construction of the complete street. That change may be influenced by the complete street, or have nothing to do with it.

In addition to within neighborhood accessibility, an important consideration is the connectivity between neighborhoods by active transportation and/or active transportation combined with transit between a neighborhood and adjacent neighborhoods where there are employment opportunities. Connectivity between neighborhoods happens as complete streets within neighborhoods become connected to those in other neighborhoods. This can be assessed by looking at whether the complete street makes such connections or is part of a planned network of complete streets.

Job Creation

Job creation estimates the number of jobs expected to change in the neighborhood or region in which the complete street/transit project is built related to the modifications in infrastructure and pedestrian and bicycle travel policies. Transportation investment can influence local employment with both temporary construction jobs and permanent jobs. Permanent jobs are defined as jobs that exist after completing construction (Harvey et al.,2018).

Most of the guidance available on job creation consists of “top-down” measures based on results from other projects. In other words, job creation resulting from previous projects is used to develop local impact indicators for use on future projects. The alternative, not discussed in the available guidance, is a “bottom-up” estimate for a complete streets/transit project and the effect of that project on the projected future built-out complete streets network if the project is a part of that network. (Harvey et al., 2018)

In a neighborhood where jobs are currently being lost, job retention may be a part of job creation. Evaluation of recent trends in jobs (increasing, static, or declining) is part of the pre-complete street comparison of different projects. Examples of job creation include construction and construction-related jobs, which would be of a more temporary nature, as well as longer-term job creation in areas such as manufacturing, food processing, wholesale trade businesses, transport by truck, employment services, food services, and drinking places, services to buildings and dwellings, management of companies and enterprises, real estate establishments, maintenance and repair construction of non-residential structures, accounting, tax preparation, bookkeeping, and payroll services (Harvey et al., 2018).

There are strong arguments that job retention and retention of talent in disadvantaged neighborhoods by making them more attractive to stay in for local residents should be a focus of investment (Brancaccio and Conlon, 2022, as an example).

For a given project, a bottom-up estimate can be made using economic projections typical in local planning techniques to estimate future job creation, preferably broken down by temporary construction jobs and permanent jobs, required qualifications or job category type, and expected pay levels. Permanent job growth can take time after a complete street is installed, and a bottom-up approach requires counting places of employment several years or longer after completion of the street. That was outside the scope of these case studies.

Recent research shows that while pedestrian and bicycle infrastructure projects create 11–14 jobs per $1 million of expenditures, highway infrastructure projects create seven jobs per $1 million of spending (Harvey et al., 2018; Garrett-Peltier, 2011; SCAG, 2016).

The methods below are suggested to measure job creation by the 2016 FHWA guidebook (Harvey et al., 2018 adapted from Semler et al., 2016):

- “Number of jobs created by construction project – measure the direct number of temporary construction jobs.
- Retail sales tax findings – track new employers and the associated number of permanent jobs attracted to the project area.
- Employment data – review Census and BLS data to track the change in employment over time.”

However, since distinguishing between permanent and temporary jobs are not easy, this study uses Garrett-Peltier study’s job category, including direct, indirect, and induced jobs. According to the definition, direct jobs are created in the engineering and construction firms which are involved in infrastructure projects. In contrast, indirect jobs are created in the supply chain of industries such as cement manufacturing, sign manufacturing, and trucking. Moreover, workers in the direct and indirect sectors spend their earnings, leading to creating demand in industries such as food services and retail establishments, resulting in the induced effects and creating induced jobs (Garrett-Peltier, 2011).

Connectivity Index

Description and Methodologies

The number and directness of travel routes and options available to a user depict connectivity, while the number of specific measures used to assess walking and bicycling connectivity in a specific area present the connectivity index (Harvey et al., 2018 adapted from Semler et al., 2016).

To use this indicator for active transportation/transit projects, first, the number of travel routes and options available to a user should be measured. The evaluation contains the number of intersections density and intersections per linear mile. These measures are defined by the number of intersections in a given land area (e.g., a square mile or acre); the number of intersections in a given land area divided by the linear network miles in the same given area; the number of linear miles of a street or other facility per given area (square mile); or the number of 3- or 4-way intersections divided by the number of intersections.

Active Transportation to Local and Regional Transit Connectivity Index

The number and connectivity of functional bicycle and walking travel routes to transit nodes that connect to within-neighborhood destinations, and the number and directness of functional bicycle and walking travel routes that connect to transit nodes that connect to out-of-neighborhood destinations are measures used to assess walking and bicycling connectivity to active transportation. The purpose of this indicator is to identify the ability to travel to and from a transit point by walking or bicycling, including considering the richness of within- and between-neighborhood transit points in a neighborhood. (Harvey et al., 2018)

The following measures can be used for calculating this indicator:

- Bicycle/ pedestrian facility density within 1 mile of a regionally significant transit or rail station: This measure, which is defined as the presence of several bicycle and/or pedestrian facilities within one mile of a regionally significant transit or rail station, depends on the location of significant transit stations, and bicycle and pedestrian facility data from local jurisdictions and transit operators. Aerial imagery or GIS can be used to calculate this measure by selecting all the bikeway/walking path segments within a 1-mile buffer of regionally significant transit stations (rail, ferry, bus rapid transit, or bus transfer stations). Then, the mileage of the total bikeway within the buffer should be divided by land area within the buffer (Harvey et al., 2018; Caltrans, 2017a).
- Number of distinct functional walking and bicycle routes with nodes at a regionally significant transit or rail station within 20 minutes of active transportation travel time. This measure relies on the location of significant transit stations, recently collected for the California State Rail Plan, and bicycle facility data from local jurisdictions and transit operators (Harvey et al., 2018; Caltrans, 2017a).

Pedestrian and Bicyclist Delay

This indicator, which is usually measured in time units (usually seconds), is related to biking and walking at specific locations such as a signalized intersection or across longer distances such as a corridor. This performance measure shows the amount of delay experienced by someone making a trip to or from a destination or transit stop through intersections or crossings. (Harvey et al., 2018)

Dunn and Pretty's Method (Dunn and Pretty, 1984; FHWA, 1998) was used to calculate the delay. Following equations were determined to calculate pedestrian delay at signalized pedestrian crossings (FHWA, 1998).

Average delay per pedestrian for a narrow roadway (about 7.5 m or two lanes)

$$d = \frac{(g+15)^2}{2(g+20)}$$

Average delay per pedestrian for a wider roadway (about 15 m or four lanes)

$$d = \frac{(g+10)^2}{2(g+15)}$$

Where

d= average delay per pedestrians, s
g= vehicular green signal, s

Table 3 and Table 4 are used to calculate the green interval duration.

Table 3. Typical Minimum Green Interval Duration (NCHRP Report 812, 2015, Table 5-3)

Phase Type	Facility Type	Minimum Green Needed to Satisfy Driver Expectancy (s)
Through	Major Arterial (speed limit exceeds 40 mph)	10 to 15
	Major Arterial (speed limit 40 mph or less)	7 to 15
	Minor Arterial	4 to 10
	Collector, Local, Driveway	2 to 10
Left Turn	Any	2 to 5

Table 4. Typical Maximum Green Duration (NCHRP Report 812, 2015, Table 5-5)

Phase Type	Facility Type	Minimum Green Needed to Satisfy Driver Expectancy (s)
Through	Major Arterial (speed limit exceeds 40 mph)	50 to 70
	Major Arterial (speed limit 40 mph or less)	40 to 60
	Minor Arterial	30 to 50
	Collector, Local, Driveway	20 to 40
Left Turn	Any	15 to 30

Level of Service

The Level of Service (LOS) indicator measures how users might perceive a service condition (e.g., safety, travel time, delay, comfort, speed) by assigning a numerical or letter score to a street based on users' safety and comfort. Various methodologies exist that can be used to assess Bicyclist Level of Service (BLOS) and Pedestrian Level of Service (PLOS) depending on context and desired outcomes (Harvey et al., 2018 adapted from Semler et al., 2016). Some active transportation and transit factors that affect the perception of LOS are lighting, and sight distances on routes and in the vegetation on the sides of routes (hiding places), level of maintenance, litter, noise, and adjacent heavy traffic (Harvey et al., 2018; Cunningham and Michael, 2004; Humpel et. al, 2002; Owen et. al, 2004).

Pedestrian LOS

Pedestrian LOS is a rating system reflecting the quality of service that pedestrians perceive from pedestrian infrastructure on a street segment, ranging from A to F (A: best, and F: worst quality of service). Two methodologies were used in this case study, including:

- Highway Capacity Manual (HCM) Methodology (Huff and Liggett, 2014)
- National Cooperative Highway Research Panel (NCHRP) Methodology (NCHRP Report 616, 2008)

In the HCM methodology, Link PLOS, Segment PLOS, Pedestrian Space LOS, and Intersection PLOS are needed to calculate the Pedestrian LOS score or Facility PLOS, which is the final score for PLOS (Figure 12).

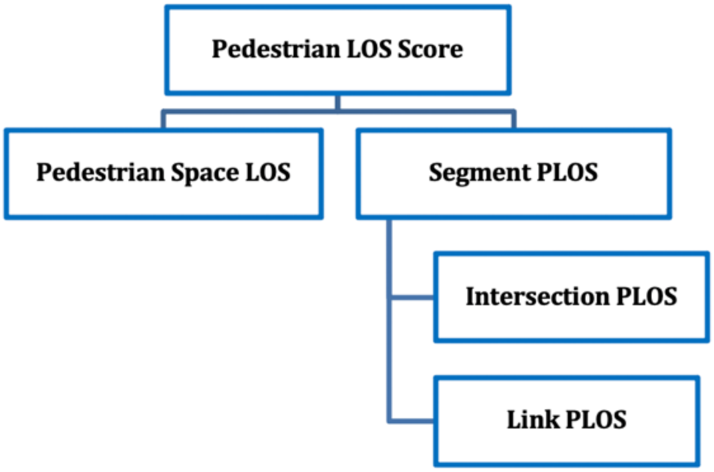


Figure 12. Pedestrian Highway Capacity Manual (HCM) Methodology (Huff and Liggett, 2014)

In the NCHRP methodology, according to the recommended set of equations (NCHRP Report 616, 2008: Chapter 7 and Chapter 8), PLOS is determined by the segment PLOS and Intersection PLOS scores, as well as the Roadway Crossing Difficulty Factor (RCDF).

The required data for calculating the PLOS, which are specified in the HCM (Huff and Liggett, 2014) and NCHRP 616 report (NCHRP Report 616, 2008), include traffic volume, speed data, roadway characteristic data (e.g., travel lane width, number of travel lanes, turn lanes, and driveway inventory), pedestrian facility characteristic data (e.g., sidewalk and buffer width, and street trees), traffic signal timing information, and land use and building data. Average pedestrian space is defined as a ratio of average space allocated to pedestrians compared to the number of pedestrians on the road. PLOS data was collected from Google Map™ and pedestrian counts using complete street planning reports and several traffic reports.

Bicycle LOS (BLOS)

Bicycle LOS (BLOS) is a rating system reflecting the quality of service that bicyclists perceive from a road segment, ranging from A to F (A: best, and F: worst quality of service). Two methodologies were used in this case study that includes (see Figure 13):

- Highway Capacity Manual (HCM) Methodology (Huff and Liggett, 2014)
- National Cooperative Highway Research Panel (NCHRP) Methodology (NCHRP Report 616, 2008)

HCM BLOS methodology requires two parameters to evaluate Facility BLOS, including Intersection BLOS and Link BLOS.

a. *HCM Methodology*

b. *NCHRP Methodology*

Figure 13. Bicycle Level of Service Methodologies

The methodology outlined in NCHRP Report 616 is used for a comprehensive BLOS analysis for the complete street. Intersection BLOS and Link BLOS should be calculated, both of which are feasible using the NCHRP methodology.

The required data for calculating the BLOS, which are specified in the HCM (Huff and Liggett, 2014) and NCHRP 616 report (NCHRP Report 616, 2008), includes traffic volume, speed data, roadway characteristic data (e.g., travel lane width, number of travel lanes, turn lanes, and driveway inventory), bicycle facility characteristic data (e.g., bicycle facility, sidewalk and buffer width, and street trees), traffic signal timing information, and land use and building data.

Urban Level of Service

Urban LOS is a rating system used to describe the quality of service that cars perceive on urban streets. Ratings vary from A (high travel speeds and slight delay) to F (severe congestion and low travel speeds). The required data for calculating the urban LOS are specified in the HCM (NCHRP Report 616, 2008). Street geometry data was collected from Google Maps™.

Transit Level of Service

Transit LOS is used to rate the quality of bus service, ranging from A to F; with the definition of:

> A: a road segment with many bus stops and frequent bus service would receive an A rating.
>
> F: a route with few bus stops, heavy delays, and infrequent service would receive an F rating.

The required data for calculating the Transit LOS are also specified in the HCM (NCHRP Report 616, 2008). Google Map™ and bus schedule maps were used to collect required data for the number of bus stops or bus frequency. A transit LOS calculator using the HCM equations was used to calculate transit LOS.

It should be mentioned that all of the LOS analyses should be done by segments. A segment begins after a controlled stop, such as an intersection or stop sign, and ends at the next controlled stop. There may be a new segment for every block in some cases, and in other cases, the segment may extend for many blocks.

Level of Traffic Stress (LTS)

Level of Traffic Stress (LTS) is a qualitative measure of the stress that bicyclists experience when biking near traffic. This semi-quantitative performance measure was not discussed in the framework of the complete street project (Harvey et al., 2018), however the authors of the current study found it useful to be included in the framework. In this performance measure, a corridor is assigned an LTS score depending on the speed limit, the geometry of the road, and the type of bike infrastructure available. Table 5 depicts the LTS scores based on the stress level the cyclists experience.

Table 5. Level of Traffic Stress (LTS) Score according to Cyclist Level of Service

Stress Level	LTS Score
None	0
Very Low	1
Low	2
Moderately Low	2.5
Moderately High	3
High	4
Very High	5

Crashes

This indicator is calculated by measuring the number of crashes or rate of crashes (crashes per volume of users) over a selected period (Harvey et al., 2018 adapted from Semler et al., 2016). According to Semler et al., 2016, the measures shown below can be used to assess the safety of the transportation system for bicycle and walking:

- Number of bicycle-involved and/or pedestrian-involved crashes over five years.
- Number of fatal or severe injuries of bicyclists and/or pedestrians over five years.
- Crashes per volume of bicyclists and/or pedestrians over five years (crash rates).

Pedestrian Miles Traveled / Bicycle Miles Traveled

Pedestrian miles traveled (PMT) and bicycle miles traveled (BMT) are indicators that measure the total miles traveled in a specific location for a particular period of time by person and bicycle, respectively. PMT and BMT are useful measures for determining the distance traveled for each mode (Harvey et al., 2018; Caltrans, 2017a).

Walking and cycling modes are more common in communities with enough destinations and facilities as well as enough appropriate inter-neighborhood connections and connections with more advantaged neighborhoods. Creating bike lanes and pedestrian lanes by complete street design can be an important factor in making active transportation more viable in disadvantaged neighborhoods, resulting in a huge improvement in PMT and BMT performance measures if the density of destinations of opportunity, transit connections, and safety issues are addressed.

According to Ewing et al.'s (2010) study, walking is related to land use diversity, intersection density, and the number of destinations within walking distance.

PMT and BMT can be calculated by multiplying the number of trips by the average trip length. The change in PMT and BMT after implementing a complete streets project indicates the project's impact. PMT and BMT encourage people to use active transportation. So, these indicators are justifiable for getting public grants. Besides, higher BMT and PMT encourage bike renting companies to invest their money into the neighborhood and improve its economy.

Street Trees

This indicator can be defined as the number of trees on a street and can be measured as tree counts, percent of street tree canopy coverage, number of trees per mile, and tree spacing. Street trees improve livability and safety by narrowing the roadway, contributing to traffic calming. Wastewater diversion, CO_2 sequestration, air quality improvement, and habitat for wildlife are some of the environmental co-benefits of street trees (Harvey et al., 2016 adapted from Semler et al., 2018). Appropriate street shade trees have a large canopy that provides a physical and psychological barrier between vehicles and pedestrians. Shade trees also cause pedestrian comfort and physical well-being, especially in warm climates, in addition to giving sidewalks a sense of security and adding beauty (Harvey et al., 2018 adapted from Change Lab Solution, 2017). The change in street trees is used to assess the impacts of a complete streets project on livability.

San Fernando Street Case Study

Access to Community Destinations

For the complete street case study, destinations within 0.5-mile walking and 2-mile bicycling radii of San Fernando Street were found using Google Earth™ and Google Maps™ (see Figure 14). The average walking speed is assumed to be three mph, while the bicycling speed is assumed to be 12 mph (Yang and Diez-Roux, 2012).

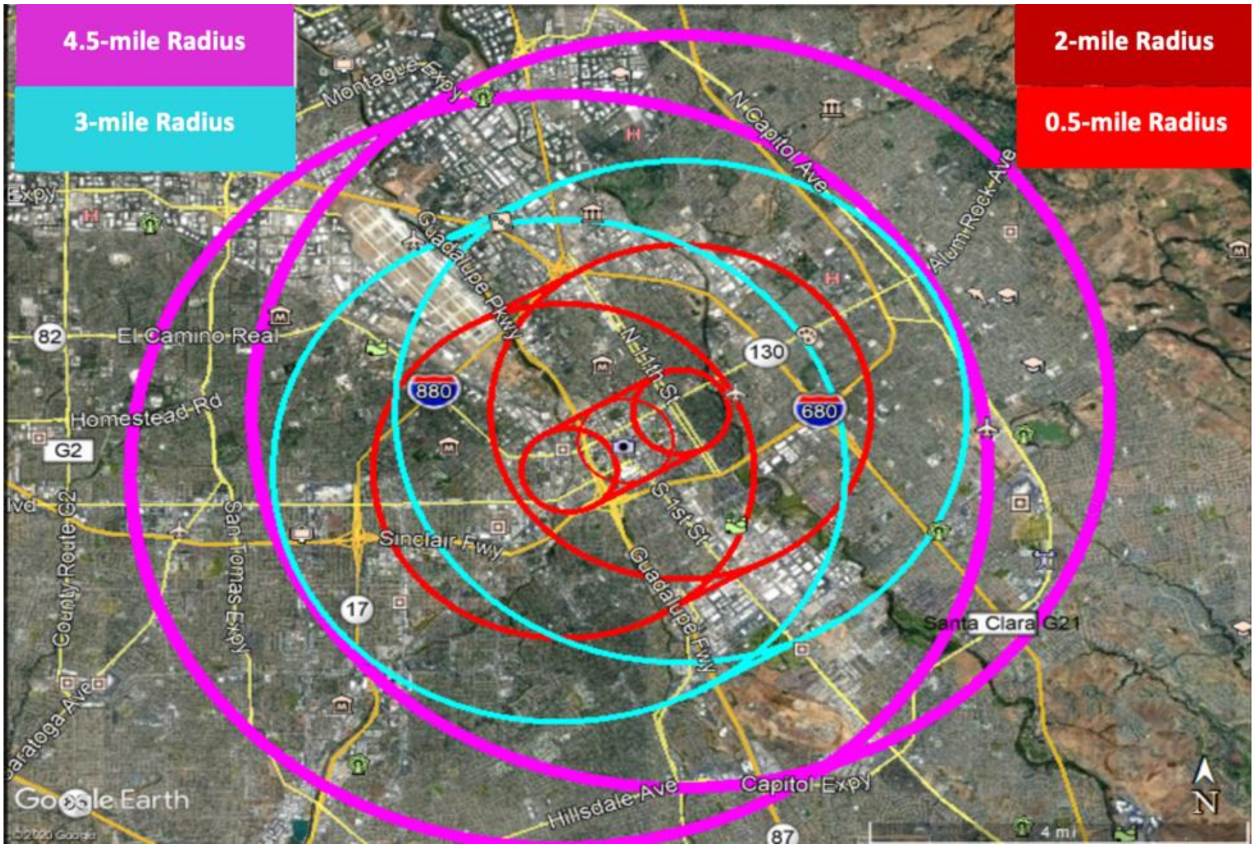


Figure 14. Access to Destination Buffer Area for Walking, Cycling, and Transit Modes of Transportation, San Fernando Complete Street Project

To consider the transit accessible area around the San Fernando complete street, there are many possibilities when combining walking and biking with train, bus, and light rail. Therefore, the most probable scenarios were selected considering 20 minutes for a combined-mode trip. The recommended buffers include 3-mile (bike and bus, bike and train, walk and light rail) and 4.5-mile (bike and light rail, bus, light rail). The list of buffers for each mode of transportation, assumptions for the speed and delay, and the calculation can be seen in Appendix A. Table 6 shows the recommended buffer distances used for different modes of transportation for 20 minute trips.

Table 6. The Recommended Buffer Distances Using in Different Modes of Transportation in 20 minutes

Recommended Buffer Distance	Mode
0.5 mile	Walking
2 mile	Biking
3 mile	Bus+Biking, Train+Biking, Light Rail+Walking
4.5 mile	Light Rail+Biking, Bus, Light Rail

The destinations considered in this case study include coffee shops, restaurants, banks, gas stations, grocery stores, pharmacies, hospitals, post offices, libraries, police stations, places of worship, and museums. The number of customers and employees for each destination was estimated using the best available resources, including government statistics, company information, and web research (see Appendix A). Access to community destinations calculations can be found in Appendix B. The calculation for a number of pharmacies, including Walgreens, CVS, and Rite Aid, is explained here as an example for the number of destinations' calculations:

- There are approximately 4 pharmacists and 6 technicians per Walgreen store. (Walgreens, 2007, Walgreens, 2020).

There are cashiers and retail workers that are working in the store as well. If the pharmacy is open between 8 am – 11 pm, and there are two 8-hour shifts, including 5 workers per shift. Thus the total employee working per day will be: 4 + 6 + (2 x 5) = **20 employees per day.**

- According to the CVS data (CVS, 2020), almost 4.5 million customers are served at 9,900 CVS stores per day in the US. Thus the total number of customers served is

  $\frac{4.5\, million\ customers}{day} \div 9900\ stores$ =**455 customers per day per store**.

  - $\frac{8\ million\ customers}{day} \div 9277 stores\ \frac{customers}{day} = \frac{862\ customers}{day}$

- Based on data from Rite Aid (Rite Aid, 2020), around 1.6 million customers visit 2,464 Rite Aid stores per day in the US. Thus the total number of customers served is

  $\frac{1.6\ million\ customers}{day} \div 2464\ stores$ = **650 customers per day per store.**

The average daily number of customers of these three popular pharmacies is thus estimated to be **635 customers per day.**

An example of access to community destinations in a 0.5-mile circular buffer for San Fernando Street in 2019 is provided in Table 7. The quantified performance measure for walking (0.5-mile), biking (2-mile), and transit (3-mile and 4.5-mile) transport modes in 2015 and 2019 (before and after building the complete street, respectively) for San Fernando Street is shown in Table 8, Table 9, and Table 10.

Table 7. Access to Community Destinations Example, in a 0.5-mile Circular Buffer for San Fernando Street in 2019

Destination Category	Coffee Shop	Restaur-ant	Bank	Gas Station	Grocery Store	Pharmacy	Hospital	Post Office	Library	Police Station	Place of Worship	Museum
Number of destinations in 0.5-mile buffer	27	142	19	8	12	9	0	2	2	1	18	6
Estimated number of employees	7	18	7	6	33	20	1,962	16	15	762	5	30
Estimated number of customers	350	230	42	682	853	350	225	71	682	100	27	273
Employee accessibility	189	2,556	133	48	396	180	0	32	30	762	90	180
Customer accessibility	9,450	32,660	798	5,456	10,236	3,150	0	142	1,364	100	486	1,638
Total Accessibility: 0.5-mile buffer	9,639	35,216	931	5,504	10,632	3,330	0	174	1,394	862	576	1,818
Total Accessibility in 0.5-mile buffer= 72641												

Example: Total Accessibility in 0.5-mile Buffer =27 (7+350) = 9639*

As observed from Table 8, Table 9, and Table 10, access to destinations along the San Fernando Street decreased for most destination types, stayed the same for some of them and increased for a few destination types from 2015 to 2019. The number of post offices, hospitals, and restaurants increased, while the number of gas stations, grocery stores, and places of worship decreased from 2015 to 2019. Access to destination decreasing can be explained by the changes in the San Fernando complete street typology that required demolishing several of the buildings around the street.

Table 8. Access to Community Destinations for Walking (0.5-mile), Biking (2-mile), and Transit (3-mile and 4.5-mile) Modes in 2015 for San Fernando Street

Buffer		**Coffee shop**	**Restaur-ant**	**Bank**	**Gas station**	**Grocery store**	**Pharmacy**	**Hospital**	**Post office**	**Library**	**Police station**	**Places of Worship**	**Museum**
0.5	Number of Destinations	37	218	24	9	13	9	0	2	2	1	23	5
	Total Accessibility:	*13,209*	*54,064*	*1,176*	*6,192*	*11,518*	*3,330*	*0*	*174*	*1,394*	*862*	*736*	*1,515*
2	Number of Destinations	55	218	44	45	69	23	0	4	9	2	93	17
	Total Accessibility:	*19,635*	*54,064*	*2,156*	*30,960*	*61,134*	*8,510*	*0*	*348*	*6,273*	*1,724*	*2,976*	*5,151*
3	Number of Destinations:	94	365	60	78	99	51	4	7	17	3	141	20
	Total Accessibility:	*33,558*	*90,520*	*2,940*	*53,664*	*87,714*	*18,870*	*8,748*	*609*	*11,849*	*2,586*	*4,512*	*6,060*
4.5	Number of Destinations	140	523	103	138	150	78	5	12	23	5	233	23
	Total Accessibility:	*49,980*	*129,704*	*5,047*	*94,944*	*132,900*	*28,860*	*10,935*	*1,044*	*16,031*	*4,310*	*7,456*	*6,969*
Total Accessibility in 0.5-mile buffer= 94,170													
Total Accessibility in 2-mile buffer= 192,931													
Total Accessibility in 3-mile buffer= 321,630													
Total Accessibility in 4.5-mile buffer= 488,180													

Table 9. Access to Community Destinations for Walking (0.5-mile), Biking (2-mile), and Transit (3-mile and 4.5-mile) Modes in 2019 (after building the CS) for San Fernando Street

Buffer (mile)		**Coffee shop**	**Restaur-ant**	**Bank**	**Gas station**	**Grocery store**	**Pharmacy**	**Hospital**	**Post office**	**Library**	**Police station**	**Places of Worship**	**Museum**
0.5	Number of Destinations	27	142	19	8	12	9	0	2	2	1	18	6
	Total Accessibility:	*9,639*	*35,216*	*931*	*5,504*	*10,632*	*3,330*	*0*	*174*	*1,394*	*862*	*576*	*1,818*
2	Number of Destinations	51	231	37	38	55	22	0	4	9	2	63	17
	Total Accessibility:	*18,207*	*57,288*	*1,813*	*26,144*	*48,730*	*8,140*	*0*	*348*	*6,273*	*1,724*	*2,016*	*5,151*
3	Number of Destinations:	81	424	57	68	96	41	5	7	16	3	126	20
	Total Accessibility:	*28,917*	*105,152*	*2,793*	*46,784*	*85,056*	*15,170*	*10,935*	*609*	*11,152*	*2,586*	*4,032*	*6,060*
4.5	Number of Destinations	135	560	94	117	144	58	6	17	22	5	201	23
	Total Accessibility:	*48,195*	*138,880*	*4,606*	*80,496*	*127,584*	*21,460*	*13,122*	*1,479*	*15,334*	*4,310*	*6,432*	*6,969*
Total Accessibility in 0.5-mile buffer= 70,076													
Total Accessibility in 2-mile buffer= 175,834													
Total Accessibility in 3-mile buffer= 319,246													
Total Accessibility in 4.5-mile buffer= 468,867													

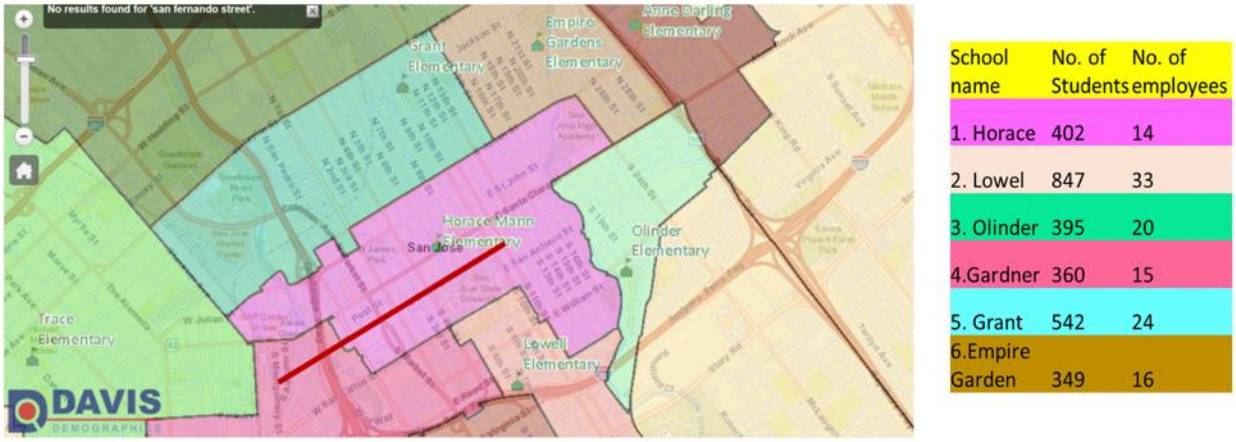
Table 10. Access to Community Destinations for Walking (0.5-mile), Biking (2-mile), and Transit (3-mile and 4.5-mile) Modes-Before the construction versus After the construction of the San Fernando Street

Total Accessibility to community Destinations	**Before**	**After**
Total Accessibility in 0.5-mile buffer (Walking)	94,170	70,076
Total Accessibility in 2-mile buffer (Bicycling)	192,931	175,834
Total Accessibility in 3-mile buffer (Transit)	321,630	319,246
Total Accessibility in 4.5-mile buffer (Transit)	488,180	468,867

Access to Schools

Results using Framework Methodology

According to the framework's suggestions, circular buffers around the complete street were considered first. However, these measurements do not seem appropriate because this area includes many schools (97 schools) in a 2-mile bicycling distance as well as different school districts, which results in complicated situations that do not consider the vulnerability of the student population. Therefore, the current study proposed a school district boundary instead of considering circular buffer areas to measure the “access to school” performance measure. A school attendance boundary, or a catchment area, is defined as a geographic area where the students are assigned to attend a local school (Figure 15).



School name	No. of Students	No. of employees
1. Horace	402	14
2. Lowel	847	33
3. Olinder	395	20
4.Gardner	360	15
5. Grant	542	24
6.Empire Garden	349	16

Figure 15. Access to school (considering school district boundary)- San Fernando StreetCase Study

Table 11 presents the access to school results according to school district boundaries within walking (0.5-mile) and bicycling (2-mile) distances. The complete list of schools, number of students, and employees for the San Fernando Street case study can be found Appendix C.

Table 11. Accessibility to School considering school district boundary in particular mile circle buffer, San Fernando Street Case Study.

Distance	Accessibility
0.5-mile (Walking)	402
2-mile (Cycling)	2,895

The Access to School indicator for both before (2017) and after (2019) completing the complete street is the same due to no change in the number of schools between these two years. However, this interpretation is not enough; because this indicator is supposed to indicate how many students have access to a complete street for going to school. Therefore, considering only the number of schools near the complete street does not adequately convey the impact of the complete street on this indicator. Hence, surveys were provided for principals to find out the accessibility of students to their schools (next section).

Survey of Principals

Access to school surveys were sent to the principals of six schools in the San Fernando Street area based on the boundary discussed earlier above. None were returned. The survey was sent out at the beginning of summer in 2020 and again later in the summer. The extra work being undertaken by principals at that time to deal with changing Covid protocols and the return to in-person teaching makes the lack of response understandable.

Access to Jobs

Locations of jobs within 0.5-mile walking and 2-mile bicycling circular buffer of San Fernando Street were found using Google Earth™ and Google Maps™. The average walking and bicycling speed are considered 3 miles per hour and 12 miles per hour, respectively (Yang and Diez-Roux, 2012). Considering delay, the average walking distance is 0.5-mile, while the average bicycling distance is 2-mile.

Like access to community destinations, considering the transit buffer area around San Fernando Street, there are many possibilities when combining walking and biking with train, bus, and light rail. Therefore, the most probable scenarios were selected considering 20 minutes for a multi-modal trip assuming 3-mile (bike and bus, bike and train, walk and light rail) and 4.5-mile (bike and light rail, bus, light rail) radii. The recommended buffer distances using different modes of transportation in 20 minutes can be seen in Table 6.

Job location types considered for this case study include office buildings, governmental buildings, coffee shops, restaurants, banks, gas stations, grocery stores, pharmacies, hospitals, post offices, libraries, police stations, places of worship, and museums. The number of employees per location was estimated using the available resources, including government statistics (U.S. government accountability Office, 2018; Virginia Tech, 2020; California State University, 2012), company information, and web research (see Appendix C).

The number of office jobs in proximity to the complete street is required. Common building codes, which are not publicly available, were used to estimate the number of employees per office building. The method to calculate the number of government and private offices employees per building using Google Earth is explained below.

According to the County of Santa Clara, where San Fernando Street is located, office workers are typically assigned 331 square feet per person, also referred to as assignable square feet (ASF) (SCCGOV, 2014). The gross square footage (GSF) of each building was measured using the measure tool in Google Maps. To estimate the ASF per building, the number of floors was multiplied by the footprint of the building to calculate the total GSF followed by use of common ratios of ASF to GSF; these ratios are 60% and 70%, according to the policies adopted by California State University system (Cal State University, 2012) and Virginia Institute of Technology (Virginia Tech, 2020). Therefore, an average value of 65% was assumed for this ratio to determine the number of employees in governmental or non-governmental office buildings near the complete street (following equation presents an example of how the measurement tool was used to evaluate the GSF of an office building in San Fernando Street.

Number of Employees for government and private offices

$$\boldsymbol{Number\ of\ Employees} = \frac{GSF * 65\%}{331\,\frac{ft^2}{Person}}$$

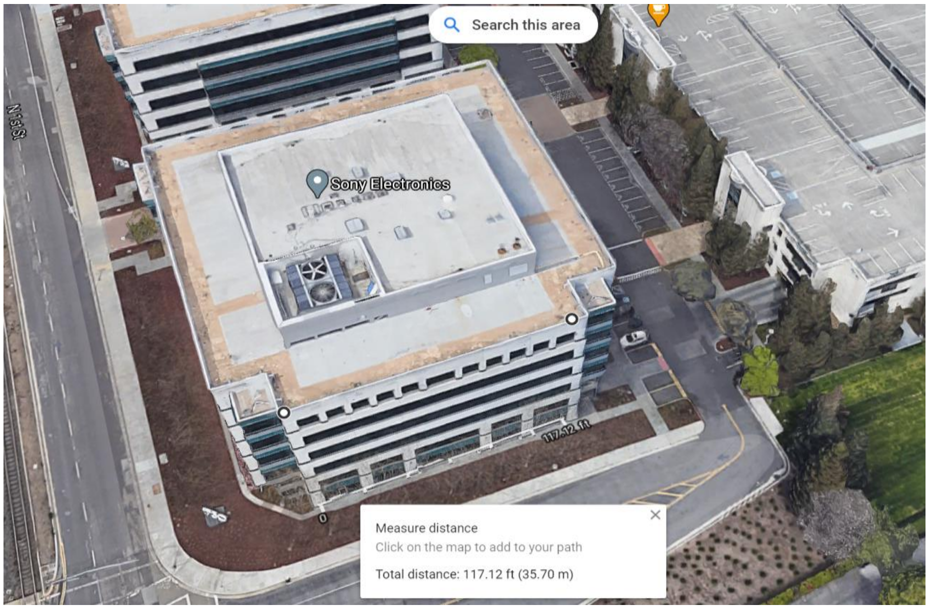


Figure 16. Example of the measurement tool used for evaluating the GSF of an office building in San Fernando Street (Google Maps™)

Table 12 and Table 13 present the results for access to jobs for walking (0.5-mile), biking (2-mile), and transit (3-mile and 4.5-mile) modes in 2015 (before building the CS) and 2019 (after building the CS), respectively, for San Fernando Street. As can be observed from Table 14, there is a slight decrease in accessibility to jobs within the walking and biking distances after the completion of complete street construction; this is likely due to the changes in the San Fernando complete street typology that required demolishing several buildings around the street.

Table 12. Access to Jobs for Walking (0.5-mile), Biking (2-mile), and Transit (3-mile and 4.5-mile) Modes in 2015 (before building the CS) for San Fernando Street

Buffer		Coffee shop	Restaurant	Bank	Gas station	Grocery store	Pharmacy	Hospital	Post office	Library	Police station	Places of Worship	Museum	Govt. Building	Office Building
0.5 miles	**Number of job sites**	37	218	24	9	13	9	0	2	2	1	23	5	12	52
	Accessibility	259	3924	168	54	429	180	0	32	30	762	115	150	3,724	1,1226
2 miles	**Number of job sites**	55	218	44	45	69	23	0	4	9	2	93	17	10	8
	Accessibility	385	3924	308	270	2277	460	0	64	135	1524	465	510	4,889	11,998
3 miles	**Number of job sites**	94	365	60	78	99	51	4	7	17	3	141	20	12	31
	Accessibility	658	6570	420	468	3267	1020	7848	112	255	2286	705	600	6,624	19,189
4.5 miles	**Number of job sites**	140	523	103	138	150	78	5	17	23	5	233	23	4	68
	Accessibility	980	9,414	721	828	4,950	1,560	9,810	192	345	3,810	1,165	690	7,064	35,001
Total Accessibility in 0.5-mile buffer= 21,053															
Total Accessibility in 2-mile buffer= 27,209															
Total Accessibility in 3-mile buffer= 50,022															
Total Accessibility in 4.5-mile buffer= 76,530															

Table 13. Access to Jobs for Walking (0.5-mile), Biking (2-mile), and Transit (3-mile and 4.5-mile) Modes in 2019 (after building the CS) for San Fernando Street

Buffer		Coffee shop	Restaurant	Bank	Gas station	Grocery store	Pharmacy	Hospital	Post office	Library	Police station	Places of Worship	Museum	Govt. Building	Office Building
0.5 miles	**Number of job sites**	27	142	19	8	12	9	0	2	2	1	18	6	12	52
	Accessibility	189	2,556	133	48	396	180	0	32	30	762	90	180	3,724	11,226
2 miles	**Number of job sites**	51	231	37	38	55	22	0	4	9	2	63	17	10	8
	Accessibility	357	4,158	259	228	1,815	440	0	64	135	1,524	315	510	4,889	11,998
3 miles	**Number of job sites**	81	424	57	68	96	41	5	7	16	3	126	23	12	31
	Accessibility	567	7632	399	408	3168	820	9,810	112	240	2,286	630	600	6,624	19,189
4.5 miles	**Number of job sites**	135	560	94	117	144	58	6	17	22	5	201	27	4	68
	Accessibility	945	10,080	658	702	4,752	1,160	11,772	272	330	3,810	1,005	690	7,064	35,001
Total Accessibility in 0.5-mile buffer= 19,546															
Total Accessibility in 2-mile buffer= 26,692															
Total Accessibility in 3-mile buffer= 52,485															
Total Accessibility in 4.5-mile buffer= 78,241															

Table 14. Access to Jobs for Walking (0.5-mile), Biking (2-mile), and Transit (3-mile and 4.5-mile) Modes- Before the construction versus After the construction of the San Fernando Street

Total Accessibility Jobs	Before	After
Total Accessibility in 0.5-mile buffer (Walking)	21,053	19,546
Total Accessibility in 2-mile buffer (Bicycling)	27,209	26,692
Total Accessibility in 3-mile buffer (Transit)	50,022	52,485
Total Accessibility in 4.5-mile buffer (Transit)	76,530	78,241

Job Creation

The Political Economy Research Institute at the University of Massachusetts, Amherst, published a research paper presenting the correlation between job creation and project budgets (Garrett-Peltier, 2011). According to this study, a total of 7.61 full-time equivalent jobs are created per $1 million spent on bike and pedestrian infrastructure projects. The data for this report were collected in the US from departments of transportation and public works departments from 11 cities and 58 separate projects. These projects include road construction and rehabilitation, building new multi-use trails, and widening roads, bike lanes, and sidewalks. The input-output economic model with state-specific data was used to estimate the employment impacts of each project.

IMPLAN version 3 is used in the Garrett-Peltier study (2011) to model job creation and the same model has been used for modeling job creation in this case study. The job creation is broken down into three categories:

- 50% Direct jobs (e.g., at the engineering/construction firm)
- 25% Indirect jobs (supply chain-related, e.g., cement/paint manufacturing)
- 25% Induced jobs (e.g., fast food, retail)

IMPLAN uses employment data as defined in the US Bureau of Economic Analysis Regional Economic Accounts and Bureau of Labor Statistics Census of Employment and Wages and is based on the full-time and part-time averages. According to this model, one job lasting 12 months is equal to two jobs lasting six months each, or a job with a three-month length is considered a 0.25 job.

The authors of the current study contacted the City of San Jose in District 3 and the city was unable to provide a response regarding whether the jobs created due to the construction of the San Fernando complete street were temporary or permanent. According to the literature review (Garrett-Peltier, 2011; SCAG, 2016), jobs are not necessarily located in the community where the complete street project is located. Therefore, since distinguishing between permanent and temporary jobs is not easy based on available data, this study used Garrett-Peltier study's job category, including direct, indirect, and induced jobs. According to the definition, direct jobs are created in the engineering and construction firms which are involved in infrastructure projects. In contrast, indirect jobs are created in the supply chain of industries such as cement manufacturing, sign manufacturing, and trucking. Moreover, workers in the direct and indirect sectors spend their earnings, leading to creating demand in industries such as food services and retail establishments, resulting in the induced effects and creating induced jobs (Garrett-Peltier, 2011).

The project budget of $9.9 million for this final project on San Fernando Street was obtained from the Active Transportation Program (ATP) Project List District documents (Caltrans, 2019; CTC, 2019). Calculation of job creation is shown below:

Jobs = Total budget x 7.61 jobs per every $1 million project budget x job category (in %)

- $9.99 * 7.61 * 50% = 38 Direct jobs
- $9.99 * 7.61 * 25% = 19 Indirect jobs
- $9.99 * 7.61 * 25% = 19 Induced jobs

From the budget of $9.99 million spent on transportation infrastructure, a total of 76 jobs were estimated to be created for the construction of the San Fernando complete street project.

Connectivity Index

A number of specific measures are used to assess walking and bicycling connectivity in a specific area. Different routes and options in a 1.3-mile rectangular buffer around San Fernando Street between Diridon station and 11 streets were calculated (see Figure 17). 1.3 mile was the measured length of the San Fernando Street complete street for this performance measure. As shown in Figure 17, three circles with a 1.3-mile diameter were drawn in the center and edges of San Fernando complete street, which resulted in a 2.6-mile by 1.3-mile rectangle when the boundaries of the three circles were connected. The area of this rectangle was then measured to calculate the connectivity index via Google Earth and Google Maps.

Figure 17. Considered area for measuring the Connectivity Index, San Fernando Street Case Study

Connectivity indices use various metrics, as also discussed in an earlier study (Harvey et al., 2018). Table 15 presents the selected indices used in the current study and the connectivity results for the San Fernando Street project. The results indicate that the connectivity was increased by the complete streets project but that the index still does not reach the value of "good connectivity" from Semler et al (2016).

Table 15. Connectivity Results for San Fernando Street Case Study Based on the Selected Connectivity Indices

Measure	**Definition and Calculation**	**Notes**	**Before complete street construction (2017)**	**After complete street construction (2019)**
Intersection Density	Number of intersections in a given land area, such as a square mile or acre.	Limited to "4-leg intersections", Typical Range For "Good" Connectivity: 100-160 (Semler et al., 2016)	281/ (2.6*1.3)= **83**	320/ (2.6*1.3)= **95**
Intersections per Linear Mile	Number of intersections in a given land area is divided by the linear network miles in the same area.	Limited to "4-leg intersections" (Semler et al., 2016)	281/2.6/ (2.6*1.3) = **64**	320/2.6 (2.6*1.3)= **73**

Active Transportation to Local and Regional Transit Connectivity Index

Aerial imagery using WHAT, Google Earth™, and a static map (City of San Jose, 2020b) was used to calculate this measure by selecting all the bikeway/walking path segments within a 1.3-mile buffer of regionally significant transit stations. The total bikeway mileage within the buffer was then divided by land area within the buffer. The 3.4 square mile (2.6 by 1.3 miles) rectangular buffer around the train station located at the intersection of First Street and San Fernando Street was considered a network area (see Figure 18) because the location of this station is almost at the center of the San Fernando Street project. Table 16 depicts the results for the active transportation transit connectivity index for the project. The results show that the San Fernando Street project resulted in a considerable increase in connectivity to transit.

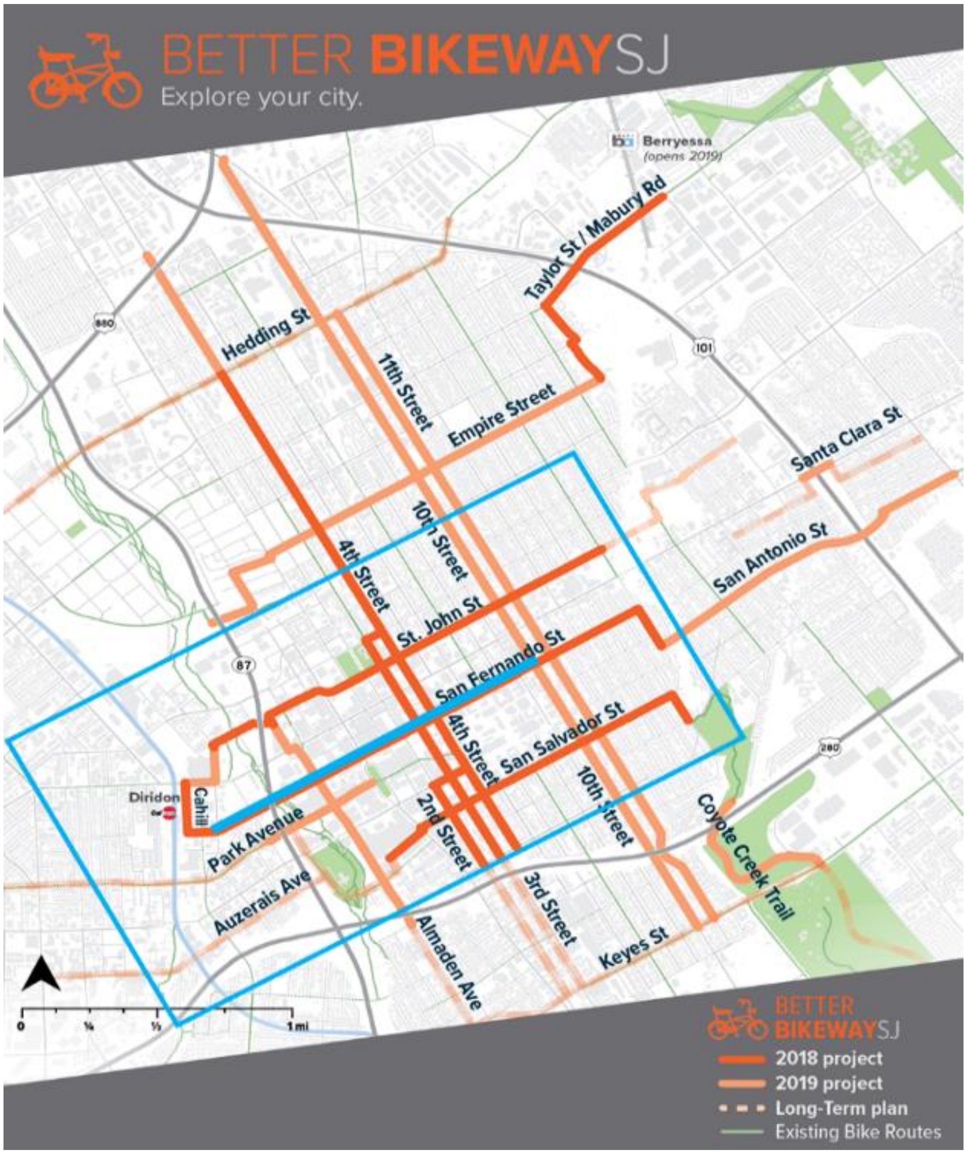


Figure 18. City of San Jose's bike network is based on the San Jose Better Bikeway Project with San Fernando Street project and transit served area highlighted in blue (overlaid on City of San Jose, 2020b)

Table 16. Results for the Active Transportation Transit Connectivity Index for San Fernando Complete Street Project

Measurement	Before the construction of complete street (2017)	After the construction of complete street (2019)
Mileage of bike/ ped. Lane (2-side)	**19.4** mile	**38** mile
Bike/ ped facility density (2-side)	19.4/(2.6*1.3)= **5.8**	38/(2.6*1.3)= **11.2**

Pedestrian and Bicyclist Delay

This indicator was calculated for 2019 (after the complete street was built) using Google Earth™ and Google Earth historical imagery features. Calculations for the total delays in a rectangular buffer (1.3-mile*2.6-mile) around the San Fernando Street project before and after the construction of the complete street are presented in Table 17 and Table 18, respectively. According to the results shown in the tables, there about a 30% increase in bicycle and pedestrian travel delays between 2017 (before the construction of complete street) and 2019 (after the construction of complete street). This indicates that the complete streets project made active transportation somewhat slower compared to before the project was built.

Table 17. Total delays in a rectangular buffer (1.3-mile*2.6-mile) around the San Fernando-Before the Complete Street Construction

g: vehicular green signal Formula	**d: Average delay (s) for narrow roadway (Minor arterial)**	**d: Average delay (s) for narrow roadway (Major arterial)**	**No. of arterial within 1.3-mile* 2.6-mile buffer (Minor Arterial)**	**No. of arterial within 1.3-mile* 2.6-mile buffer (Major Arterial)**	**Total delay(s) for Minor arterial**	**Total delay(s) for Major arterial**	**Total delay(s) in 1.3mile* 2.6mile buffer**
minimum green interval duration:	d= [(7+15)^2]/ [2*(7+20)]= **9 s**	d= [(11+10)^2]/ [2*(11+15)]= **8.5**	16	26	144	221	**365**
Minor arterial: 4-10 s (avg 7 s)							
Major arterial: 7-15 s (avg 11 s)							
maximum green interval duration:	d= [(40+15)^2]/ [2*(40+20)]= 25.2~ **25 s**	d= [(50+10)^2]/ [2*(50+15)]= 27.7 ~ **28**	16	26	400	588	**988**
Minor arterial: 40-50 s (avg 40 s)							
Major arterial: 40-60 s (avg 50 s)							
Average Delay					272	405	**677 sec (11min)**

Table 18. Total delays in a rectangular buffer (1.3-mile*2.6-mile) around the San Fernando - After the Complete Street Construction

g: vehicular green signal Formula	d: Average delay (s) for narrow roadway (Minor arterial)	d: Average delay (s) for narrow roadway (Major arterial)	No. of arterial within 1.3-mile* 2.6-mile buffer (Minor Arterial)	No. of arterial within 1.3-mile* 2.6-mile buffer (Major Arterial)	Total delay(s) for Minor arterial	Total delay(s) for Major arterial	Total delay(s) in 1.3mile* 2.6mile buffer
minimum green interval duration: Minor arterial: 4-10 s (avg 7 s) Major arterial: 7-15 s (avg 11 s)	d= [(7+15)^2]/ [2*(7+20)]= **9 s**	d= [(11+10)^2]/ [2*(11+15)]= **8.5**	19	30	171	255	**426**
maximum green interval duration: Minor arterial: 40-50 s (avg 40 s) Major arterial: 40-60 s (avg 50 s)	d= [(40+15)^2]/ [2*(40+20)]= 25.2~ **25 s**	d= [(50+10)^2]/ [2*(50+15)]= 27.7 ~ **28**	19	30	475	840	**1315**
Average Delay					323	548	**871 sec (14min)**

Level of Service

PLOS and BLOS

The problem in calculating PLOS and BLOS for the San Fernando Street case study was a lack of traffic data before the construction of the complete street, making a before-and-after comparison of LOS difficult. Table 19 to Table 23 show the PLOS and BLOS results for the complete street project using the HCM and NCHRP methodologies (as discussed in Sections above).

Table 19. NCHRP Link PLOS for San Fernando Case Study

	Before	After
Link PLOS Number	4.12	4.12

Due to the lack of traffic data before the construction of the complete street project, it is difficult to calculate how NCHRP Link PLOS changed Table 19 shows the link PLOS score assuming the same traffic data before and after the construction of the complete street project. A letter grade cannot be assigned to the NCHRP Link PLOS value because the letter LOS grade applies only to the full facility score and not to the link score. Besides, without calculating intersection BLOS, there is a lack of data; NCHRP PLOS was not recommended.

Table 20. Segment-Based LOS by Average Pedestrian Space for San Fernando Complete Street

Methodology	Before complete street was built	After complete street was built
Segment-Based LOS by Average Pedestrian Space	A (309)	A (309)

The sidewalks were wide both before and after the construction of the San Fernando complete street. Since the road's width which is measured inside of the lane to the curb did not change (just re-striped), the pedestrians’ proximity to the traffic remained unchanged; therefore, PLOS by average pedestrian space did not change as can be seen in Table 20.

Table 21. HCM Link PLOS for San Fernando Complete Street

	Before complete street was built		After complete street was built	
HCM Link PLOS	NB	SB	NB	SB
	B	B	B	B
	B (1.95)		B (1.95)	

**NB: North Bound, and SB: South Bound*

HCM link PLOS didn’t change, as can be seen in Table 21 because there is no change in the distance between the traffic lanes and the sidewalk. The sidewalks were already spacious in the downtown area that San Fernando Street cuts through. Due to lack of data, HCM intersection BLOS analysis of the complete street was not done, Table 22 presents only HCM link BLOS.

Table 22. HCM Link BLOS Before and After Construction of San Fernando Complete Street

	Before complete street was built		After complete street was built	
Link BLOS	NB	SB	NB	SB
	C	C	C	C
	C (3.34)		C (3.34)	

Some significant safety improvements can be observed in San Fernando Street complete street, including fresh green paint, plastic bollards to protect the bike lane, and putting the bike lane on the other side of on-street parking. However, some of the important parameters that the HCM methodology considers (e.g., bike lane width) did not change as can be seen in Table 22. The HCM methodology considers the road's width instead of the bike lane's width or consideration of the bike lane separation from the road. Therefore, the use of a different BLOS methodology is suggested when Class IV bike lanes are involved. Since HCM does not provide a way to consider the presence of these safety elements, HCM BLOS is not always the best methodology for analyzing complete street projects.

The recommended set of BLOS using the NCHRP equations (NCHRP Report 616, 2008, Eq. 30-32) for the entire facility was calculated. Unlike the HCM methodology, calculating Intersection BLOS is quite doable and is not too data intensive.

Table 23. NCHRP Link BLOS Before and After the Construction of San Fernando Complete Street

	Before complete street was built		After complete street was built	
Link BLOS	NB	SB	NB	SB
	D	D	D	D
	D (3.83)		D (3.83)	

The constant score of BLOS before and after constructing the complete street indicates that the NCHRP BLOS methodology is not appropriate for Class IV bike lanes since this methodology's equations and parameters do not match up well. For instance, the width of paving between the outside lane stripe and the edge of the pavement is the shoulder of the road for a Class II bike lane. If there is no shoulder and a barrier with a bike lane on the other side, the input distance is unclear. In addition, the inflexibility of the NCHRP BLOS equations limits the applicability of this model and makes it less useful.

LOS of score 'D' seems to be low for this complete street project (even if given to this street before constructing the complete street). The NCHRP methodology is very sensitive to the number of access points (e.g., driveways, side streets, two-way stop intersections), resulting in a much lower LOS score for segments with higher access point density (see Table 23). There are many parking lots and side streets which result in unacceptable BLOS scores.

Although it is evident that cyclist safety along the complete street did improve from 2013 to 2019, there is no change in NCHRP and HCM BLOS. Safety improvement was achieved by improving lane striping and marking and moving the bike lane to the other side of the parking lane. The BLOS methodologies were not designed to analyze such bike lanes, so they could not accurately reflect the improvements in bike safety. Therefore, Bicycle Level of Traffic Stress (LTS), which can be applied to all of these scenarios, is the recommended approach for all complete street projects instead of BLOS methodologies (HCM and NCHRP) which may be useful in certain contexts.

Urban LOS

Equations for calculating urban LOS are derived from chapter 18 of HCM (Harvey et al., 2018 adapted from HCM, 2016). LOS for a segment is determined based on travel speed. Travel speed is influenced by on-street parking, curbs, medians, segment length, and the number of access points. It should be noted that shorter segments have slower travel speeds (Table 24). Data on average daily traffic (ADT) was collected from the San Fernando Street case study's interactive traffic map (City of San Jose, 2020c).

Table 24. Travel Speed Threshold by Base Free-Flow Speed (mi/h) (HCM, 2016)

LOS	Travel Speed Threshold by Base Free-Flow Speed (mi/h)						
	55	**50**	**45**	**40**	**35**	**30**	**25**
A	>44	>40	>36	>32	>28	>24	>20
B	>37	>34	>30	>27	>23	>20	>17
C	>28	>25	>23	>20	>18	>15	>13
D	>22	>20	>18	>16	>14	>12	>10
E	>17	>15	>14	>12	>11	>9	>8
F	≤17	≤15	≤14	≤12	≤11	≤9	≤8
F	Any						

According to the FHWA Traffic Data Pocket Guide (FHWA, 2018), the hourly design volume should be around 8% of the average daily traffic (ADT). This amount (8% suggested by FHWA, 2018) is higher than the amount of ADT divided by 24 hours (4.16%). ADT for San Fernando Street was determined to be 9,957 (City of San Jose, 2020c), and multiplying ADT by 8% gives 797 vehicles per hour. Since there are no traffic data from after the completion of complete street, the same value for before and after was used. The important factors that affect Urban LOS are the number of lanes, the number of access points, and the speed limit that did not change after the completion of the complete street; therefore, no change in the score is seen for Urban LOS.

Table 25. Urban Streets Level of Service for Before and After the Construction of San Fernando Complete Street

Segment	Travel Speed (mph)	LOS	Segment Length (feet)	BFFS*
Cahill to S Montgomery	13.9	E	255	36.9
Montgomery to S Autumn	11.8	E	247	36.9
S Autumn to Delmas	19.4	C	709	33.5
Delmas to Almaden	24.1	C	1395	37.5
Almaden to Market	22.6	B	990	25.7
Market to 1st	17.5	C	550	33.5
1st Street to 2nd Street	13.4	E	265	35.3
2nd Street to 3rd Street	13.3	E	265	35.3
3rd Street to 4th Street	12.7	E	255	35.4
4th Street to 7th Street	22.9	B	1082	32.2
7th Street to 9th Street	17.9	C	716	31.2
9th Street to 10th Street	12.2	E	276	33.9
10th Street to 11th Street	13.9	E	279	33.9
Weighted average Speed	**19.4**			**33.2**
Travel Speed/BFFS = LOS	**58.20%**	**C**		

**BFFS is Base Free Flow Speed*

Urban LOS is scored based on how fast traffic moves compared to the BFFS.

As shown in Table 25, LOS C indicates that the traffic flow is about half of the base free-flow speed (BFFS). The calculation of intersection LOS is required to determine the amount of delay experienced by vehicles at signalized intersections and analyze an Urban LOS. Due to a lack of signal timing data and detailed traffic movement data, the intersection LOS could not be calculated.

An article published in the San Jose Mercury News was used to determine how intersection LOS along San Fernando Street had been affected by constructing the complete street (Pizarro, 2019). According to the article, the Santa Clara Valley Transportation Authority needed to find a different bus route for the buses on San Fernando Street because of heavy traffic congestion. Significant bus delays resulted in re-routing most of San Fernando Street bus service to a parallel street (Santa Clara Street)

Transit LOS

Transit LOS (TLOS) measures the quality of service provided by buses along with the facility by segment. The HCM methodology (NCHRP 616, 2008) and the Transit LOS Calculator (TCRP) were used to calculate TLOS of San Fernando Street (TRB, 2013). Transit LOS depends on the frequency of bus services, road geometry, and PLOS.

Required Steps for calculating the Transit LOS include:

- the transit vehicle running speed
- the travel speed of transit vehicles along the segment
- the effective width of the sidewalk

- the pedestrian link LOS.

Due to severe congestion issues being experienced on the San Fernando Street complete street, most bus stops were moved to other streets (six bus stops from San Fernando Street were moved. The current bus stops (two bus stops) operate at transit LOS C, while the rest of the segment has an automatic LOS F score due to the lack of bus stops (see Table 26). Transit LOS for the San Fernando Street complete street before construction could not be calculated because of the lack of data on the historical bus schedules. Table 26 presents the Transit LOS after the construction of San Fernando complete street.

Table 26. Transit LOS after the construction of San Fernando complete street

Segment	Score	LOS	Segment Length (feet)
Cahill to S Montgomery	6.29	F	255
Montgomery to S Autumn	6.32	F	247
S Autumn to Delmas	6.27	F	709
Delmas to Almaden	6.24	F	1395
Almaden to Market	6.24	F	990
Market to 1st	6.31	F	550
1st Street to 2nd Street	6.22	F	265
2nd Street to 3rd Street	6.23	F	265
3rd Street to 4th Street	6.23	F	255
4th Street to 7th Street	6.24	F	1082
7th Street to 9th Street	3.16	C	716
9th Street to 10th Street	3.23	C	276
10th Street to 11th Street	3.25	C	279
Weighted Average Score	**5.73**		
Weighted average LOS		**F**	

Level of Traffic Stress (LTS)

The methodology in the Montgomery County Bicycle Master Plan (Montgomery County Bicycle Master Plan, 2018) was used to measure LTS for San Fernando Street. LTS improved from 2.5 to 1 after the San Fernando Street complete street was built, as shown in Table 27. LTS score 1 indicates very low traffic stress, which is suitable for most of the vulnerable groups. The tables from the appendix of the Montgomery Master Plan (2018) used to arrive at the scores are presented in Appendix D.

Table 27. Level of Traffic Stress (LTS) Score Comparing Before and After Building the San Fernando Complete Street

LTS Method	Before complete street was built	After complete street was built
Intersection LTS	1	1
Bike Lane LTS	2.5	1
Separated Bike Lane LTS	NA	1
Summary	**2.5 (Moderately Low)**	**1 (Very Low)**

Crashes

For the San Fernando Street complete street project, the number of bicycle-involved and pedestrian-involved crashes over five years were considered. The San Jose crash table 2015-2019 database was used for this measurement (City of San Jose, 2020d). The 1.3-mile buffer areas around San Fernando complete street were considered for calculating this indicator.

Table 28. Number of Crashes in the 1.3-mile buffer areas around San Fernando complete street

<table>
<tr><th>Years</th><th>Number of Crashes</th><td rowspan="5">Before the complete street was build= Average (2015-2018) = (85+81+68+83)/4 = 79</td></tr>
<tr><td>2015</td><td>85</td></tr>
<tr><td>2016</td><td>81</td></tr>
<tr><td>2017</td><td>68</td></tr>
<tr><td>2018</td><td>83</td></tr>
<tr><td>2019</td><td>92</td><td>After the complete street was build= 92</td></tr>
</table>

Table 28 presents the crash performance measure before and after the transition of San Fernando Street to the complete street. The crash data show fluctuations before the project was built, and a small increase in crashes after the project was completed. These results are inconclusive but indicate that the crash levels should continue to be monitored to see how the project influenced crash risks. This statistic should probably be normalized by pedestrian and bicycle miles traveled, because an increase in miles traveled will increase the risk of crashes.

Pedestrian Miles Traveled / Bicycle Miles Traveled

According to the San Jose traffic planning report, walking and biking trips were modeled for the City of San Jose (Hexagon, 2018). PMT and BMT depend on the number of pedestrian trips and bicyclist trips and the distance traveled. PMT and BMT are calculated for average trip lengths of 0.5 miles and 2 miles.

Bike and pedestrian data and projections were gathered on the number of bicycle and pedestrian trips, followed by multiplying them by the respective distances.

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0.5 miles and 2 miles. Bike and pedestrian data and projections were gathered on the number of bicycle and pedestrian trips, followed by multiplying them by the respective distances.

Projections are based on the Metropolitan Transportation Commission (MTC)'s regional model. According to the model calibrated to 2015 traffic data, the mean squared error (MSE) was 34%, the R squared was 87%, and the projections were made to 2040 based on the general plan. The model gives the number of biking and walking trips within downtown San Jose and to/from downtown San Jose. Based on the general plan 2040, bike mode share and pedestrian mode share will increase by 0.01% and 2 % for Downtown San Jose, respectively (Hexagon, 2018). Table 29 presents PMT and BMT for average trip lengths of 0.5 miles and 2 miles for the entire downtown San Jose area, not just the San Fernando Street complete street area. An increase in PMT and BMT was seen that may be partly associated with the San Fernando complete street, as well as other city policies.

Table 29. Pedestrian Miles Traveled, and Bicycle Miles Traveled for San Fernando Street Case Study for Entire Downtown San Jose (not just the complete street)

Year	Trip Length	PMT	BMT
Before complete street is built (2015)	0.5 miles	7,799	2,279
	2 miles	31,194	8,916
After complete street is built (2040)	0.5 miles	31,135	6,101
	2 miles	124,540	24,404

Street Trees

The number of trees was counted along San Fernando Street from Diridon Station to the 11th Street. San Jose's Interactive TreeMap was used to count Street Trees (Figure 19). (City of San Jose, 2020e)

Figure 19. Trees Map view of San Fernando Street (taken from City of San Jose, 2020e)

Table 30. Number of Street Trees along the San Fernando Complete Street

Year	Number of street trees
2013 (before building the complete street)	136
2019 (after building the complete street)	127

As can be observed from Table 30, the number of street trees has slightly decreased because of the redesign of the San Fernando Street as a complete street.

Franklin Boulevard Case Study

Access to Community Destinations

For the complete street case study, destinations within 0.5-mile walking and 2-mile bicycling radii of Franklin Boulevard were found using Google Earth™ and Google Maps™ (see Figure 20). The average walking speed is assumed to be three mph, while the bicycling speed is assumed to be 12 mph (Yang and Diez-Roux, 2012).

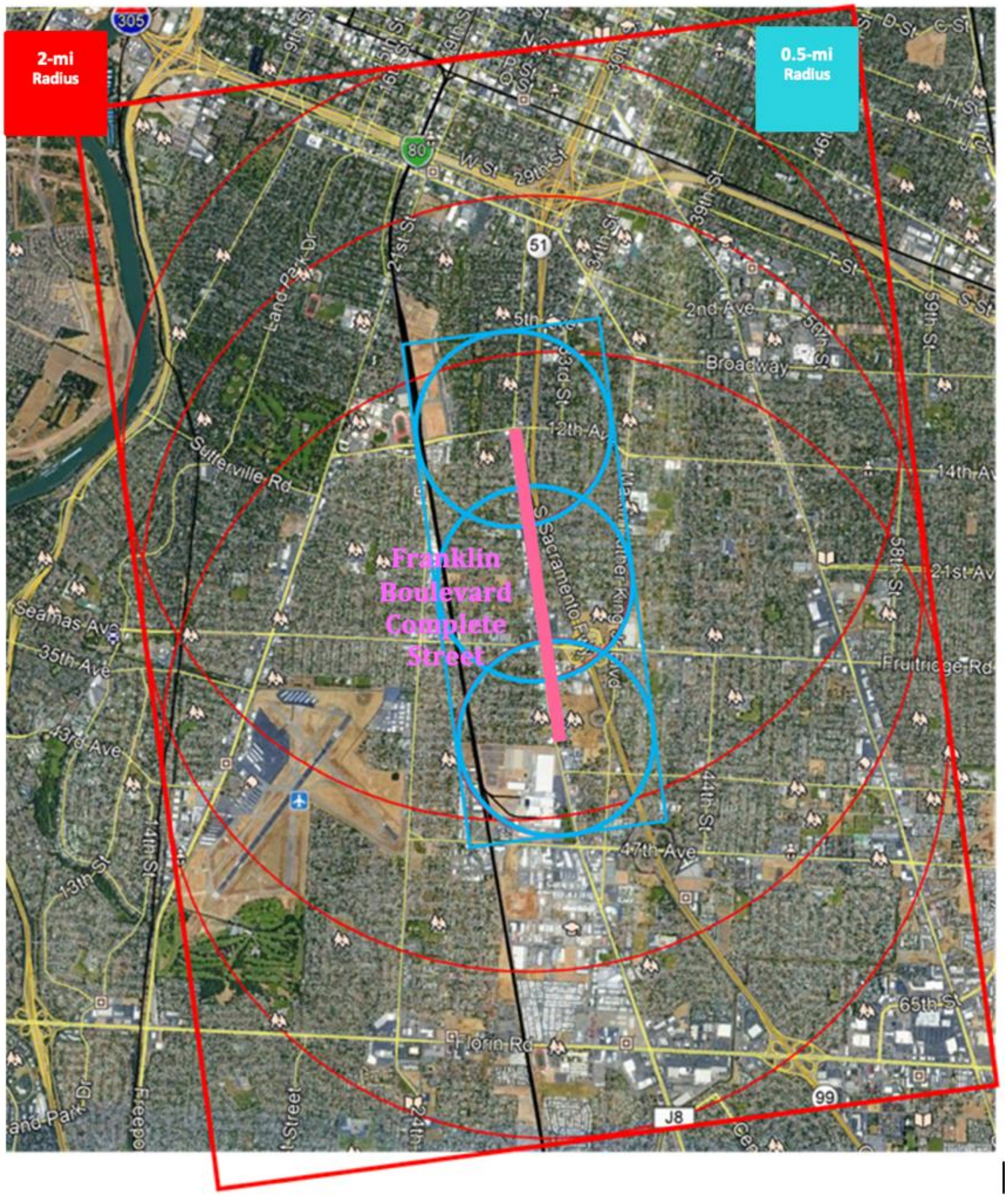
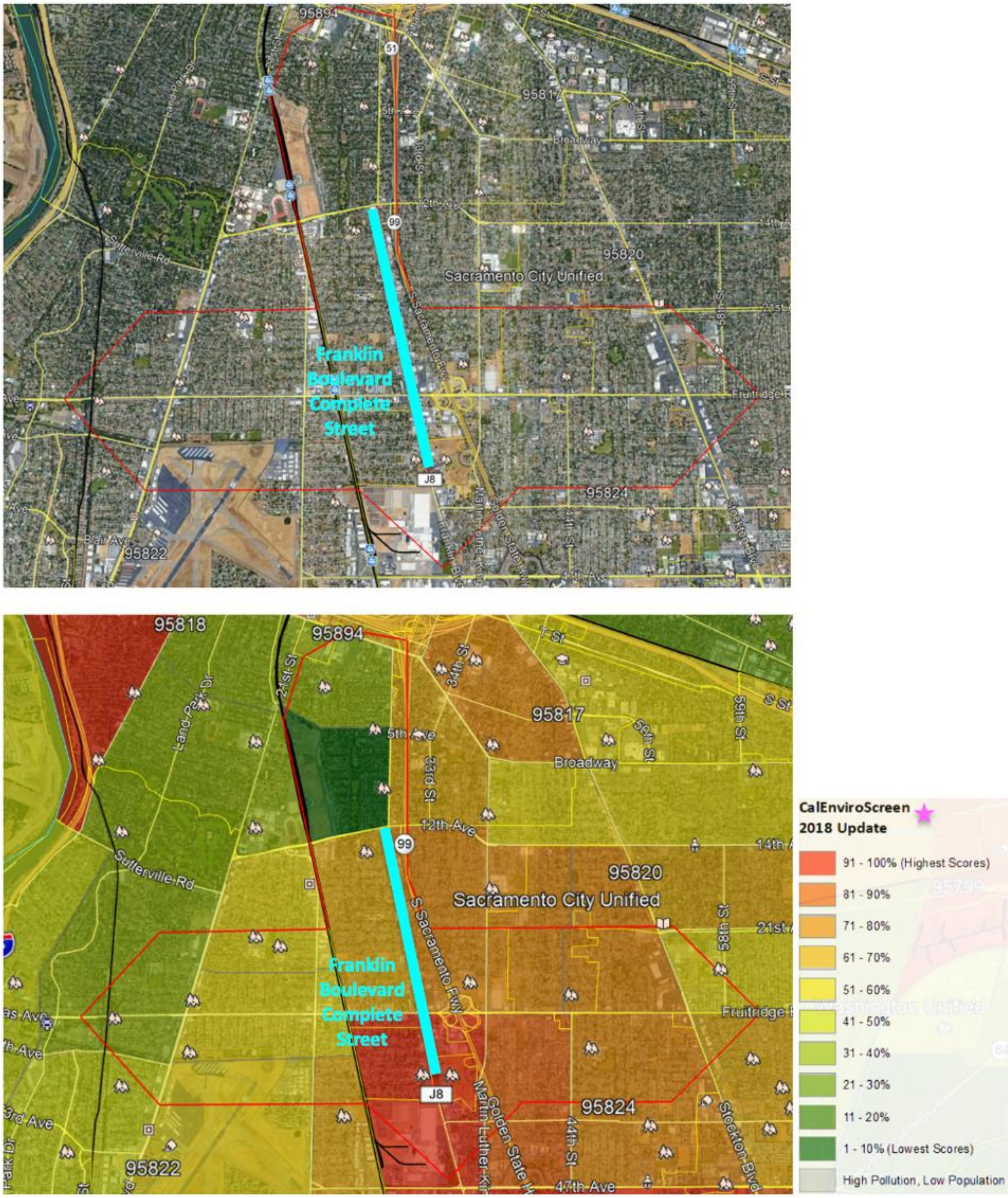


Figure 20. Access to Destination Buffer Area for Walking and Cycling Modes of Transportation, Franklin Boulevard Complete Street Project

To consider the transit accessible area around Franklin Boulevard, there are many possibilities when combining walking and biking with train, bus, and light rail. Therefore, the most probable scenarios were selected considering 20 minutes for a combined-mode trip.

The first option that can be considered around the Franklin Boulevard complete street is a circular buffer. However, due to geographical barriers and variability in population around this project, the circular buffer is too simple and cannot encompass the barriers created by the freeway and the railroad around the future complete street. Therefore, a polygon buffer was used to define the distance-time boundaries for the street, as shown in Figure 21. As seen in the proposed polygon buffer, the south part of the Franklin Boulevard complete street has a higher socio-economic score compared to the north part. It can also be observed from this figure that the southern part and the eastern part of the Franklin Boulevard complete street are a transit desert area (there is no transit service). State Route 99 is considered an eastern side geographical boundary for Franklin Boulevard complete street, while the Sacramento South Railroad is regarded as a west side geographical boundary. According to Google Map, Google Earth, and CalEnviroScreen Map (Figure 21), since Fruitridge Road includes many bus stations and light rail stations, the geographical boundary around the intersection of Franklin Blvd and Fruitridge Road is considered to be 2-mile from the eastern and 2-mile from the western side of Franklin Boulevard (10 minutes for each side). In addition to considering 10 minutes of transit, 10 minutes of walking mode (0.5 miles) is also considered around Fruitridge Road (Figure 21).



** an area with a high score experiences higher cumulative impacts (combination of pollution burden and population characteristics).*

Figure 21. Access to Destinations Buffer Area for Transit Modes of Transportation, Franklin Complete Street Project

Table 31 shows the recommended buffer distances used for different modes of transportation for 20-minute trips.

Table 31. The Recommended Buffer Distances Used for Different Modes of Transportation for 20-minute Trip

Recommended Buffer Distance	Mode
0.5 mile (Figure 20)	Walking
2 mile (Figure 20)	Biking
Polygon Buffer Area (Figure 21)	Bus+Walking, Train+Walking, Light Rail+Walking

Destinations considered for this case study include coffee shops, restaurants, banks, gas stations, grocery stores, pharmacies, hospitals, post offices, libraries, police stations, places of worship, and museums. The number of customers and employees for each destination was calculated using the best available resources, including government statistics (Appendix B), company information, and web research. The example calculations were shown earlier in the San Fernando complete street case study. Table 32 shows the example of access to community destinations in a 0.5-mile circular buffer for Franklin Boulevard in 2019. Table 33 presents the data for this performance measure for walking (0.5-mile), biking (2-mile), and transit (polygon buffer) modes for the polygon area considering the freeway and railroad barriers before the construction of the Franklin Boulevard complete street. As shown in Figure 21, the Franklin Boulevard project area is a transit desert. Therefore, the cycling buffer around Franklin Boulevard complete street project gives more accessibility to community destinations compared to the transit buffer area around the complete street project.

One of the main reasons for constructing the Franklin Boulevard complete street is to help create social development and economic revitalization for this area. According to the Franklin Boulevard economic development plan (Hernandez, 2016), there needs to be an improvement in the accessibility to the community destinations for the Franklin Boulevard. Several potential projects suggested by the economic development plan include a senior living center, a park, an expanded veterinary clinic, an education center, and a small transit-oriented development. According to the Franklin Boulevard complete street project design for 2040, a report prepared for SACOG in 2018 published as “Franklin Boulevard Complete Street Phase 2”, accessibility to community destinations will increase about 11% (City of Sacramento and Department of Public Works, 2018) because of the complete street. Figure 23 shows the access to community destinations for walking (0.5-mile), biking (2-mile), and transit (polygon buffer) transport modes before the construction and expected after the construction of the Franklin Boulevard complete street project. The Franklin Boulevard complete street construction has not yet started, therefore the results shown in Table 34 are estimates.

Table 32. Details of Access to Community Destinations in a 0.5-mile Circular Buffer for Franklin Boulevard in 2019

Destination category	**Coffee shop**	**Restaurant**	**Bank**	**Gas station**	**Grocery store**	**Pharmacy**	**Hospital**	**Post office**	**Libraries**	**Police station**	**Places of Worship**	**Museum**
Number of destinations in 0.5-mile buffer	3	27	1	5	12	3	0	0	0	1	19	0
Estimated employees	7	18	7	6	33	20	1,962	16	15	762	5	30
Estimated customers	350	230	42	682	853	350	225	71	682	100	27	273
Employee accessibility	21	486	7	30	396	60	0	0	0	762	95	0
Customer accessibility	1,050	6,210	42	3,410	10,236	1,050	0	0	0	100	513	0
Total Accessibility: 0.5-mile buffer	**1,071**	**6,696**	**49**	**3,440**	**10,632**	**1,110**	**0**	**0**	**0**	**862**	**608**	**0**
Total Accessibility in 0.5-mile buffer= 24,468												

Example: Total Accessibility in 0.5-mile Buffer =3 (7+350) = 1071*

Table 33. Access to Community Destinations for Walking (0.5-mile), Biking (2-mile), and Transit (Polygon Buffer) Modes in 2019 (before building the CS) for Franklin Boulevard

Buffer		Coffee shop	Restaur-ant	Bank	Gas station	Grocery store	Pharmacy	Hospital	Post office	Library	Police station	Places of Worship	Museum
0.5	Number of destinations	3	27	1	5	12	3	0	0	0	1	19	0
	Total Accessibility:	1,071	6,696	49	3,440	10,632	1,110	0	0	0	862	608	0
2	Number of destinations	26	125	18	42	51	22	2	4	7	2	110	1
	Total Accessibility:	9,282	31,000	882	28,896	45,186	8,140	4,374	348	4,879	1,724	3,520	303
Polygon Buffer	Number of destinations	4	44	5	14	20	6	0	0	1	1	33	0
	Total Accessibility:	1,428	10,912	245	9,632	17,720	2,220	-	-	697	862	1,056	-
Total Accessibility in 0.5-mile buffer= 24,468													
Total Accessibility in 2-mile buffer= 138,534													
Total Accessibility in Polygon Transit buffer= 44,772													

Table 34. Access to Community Destinations for Walking (0.5-mile), Biking (2-mile), and Transit (Polygon buffer) Transport Modes-Before the construction versus After the construction of the Franklin Boulevard Complete Street Project

Total Accessibility to community Destinations	**Before**	**After**
Total Accessibility in 0.5-mile buffer (Walking)	24,468	27,159
Total Accessibility in 2-mile buffer (Bicycling)	138,534	153,773
Total Accessibility in Polygon buffer (Transit)	44,772	49,697

Access to Schools

Results using Framework Methodology

In the Franklin Boulevard complete street case study, school district boundaries around the complete street between 12th Avenue and 38th Avenue were considered. However, the school district boundaries for this case study do not seem appropriate because of the large number of schools (81 schools) in the Sacramento City Unified School District, which results in complicated boundaries. Therefore, the current case study used a City of Sacramento neighborhood map to consider a 0.5-mile walking and 2-mile bicycling circular buffer around the complete street (Figure 22). Then, accessibility to the schools encompassed by the neighborhoods located within the walking and bicycling circular buffers around the complete street was calculated.

Table 35 presents the access to school results according to the Franklin Boulevard complete street project neighborhood map and walking and bicycling circular buffers around the project including two schools within a 0.5-mile and 14 schools within a 2-mile circular buffer. A third school at the south end of the complete street was previously within the 0.5-mile buffer, but was closed. Students from that school in particular would primarily be using the complete street to get to their newly assigned school near the middle of the complete street. The complete list of schools and the number of students for the Franklin Boulevard case study can be found in Appendix C.

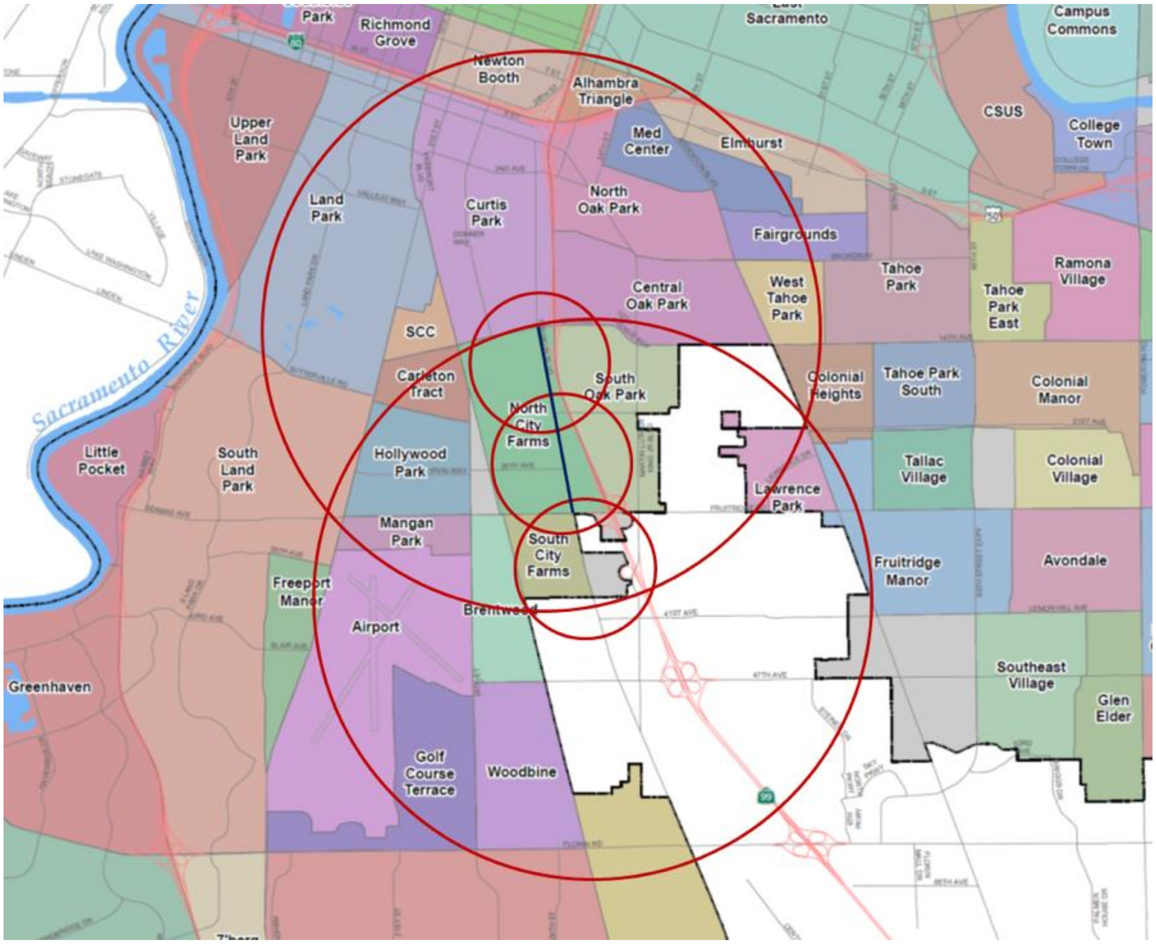


Figure 22. Combination of a city of Sacramento's neighborhood map showing a 0.5-mile walking and 2-mile bicycling circular buffer around the Franklin Boulevard case study.

Table 35. Accessibility to School considering school district boundary in particular mile circle buffer, Franklin Case Study.

Situation	**Accessibility**
d: 0.5-mile (Walking)	762
d: 2-mile (Cycling)	7,666

No information regarding any change in the number of schools and students was found. The access to school indicator for both before and after constructing the complete street was assumed the same due to no change in the number of schools between these two years.

Surveys of Principals

Access to school surveys were sent to the principals of 18 schools in the Franklin Boulevard study area based on the boundary discussed above. One was returned from an elementary school that is within the biking buffer but outside the walking buffer. That school is also on the east side of the State Route 99 freeway that cuts off most access between the Franklin

Boulevard complete street and the school and the school is therefore in a different neighborhood. The survey was sent out at the beginning of summer in 2020 and again later in the summer. The extra work being undertaken by principals at that time to deal with changing Covid protocols and the return to in-person teaching makes the lack of response understandable. The one response to the survey to the survey provides useful qualitative and quantitative answers from the principal who responded and suggests that further use of the survey instrument in future research will provide important information that cannot be obtained otherwise.

The principal estimated that 30 to 50% of students walked, depending on the season (most in spring, least in winter, fall in between), 5% biked, 10% took transit, and 35 to 55% were driven, again with seasonal differences mirroring those walking. It was estimated that those who walk have about a 5-minute trip. The percentages of students who walked without adult supervision (a sub-set of the total who walk) increases from 7% in kindergarten, to 10% for grades 1-3, and 15% for grades 1-5.

The principal identified that those students using active transportation mostly do not use Franklin Boulevard and identified two other schools (another elementary school and a middle school) whose students would be more likely to use it, in neighborhoods that are not isolated from the school by the freeway. Although the school is three blocks from Franklin Boulevard and in the Franklin Boulevard biking and walking buffers, the principal identified another boulevard that is diagonal to Franklin, roughly parallel to and then intersecting Franklin, that students use and whose safety issues would be more important because its conditions are a challenge for those wanting to use active transportation. In particular, the principal identified the presence of liquor stores and gatherings of homeless people at those stores, and the high volume of vehicle traffic traveling past the school coming from students using a nearby high school. The former issue cannot be addressed by a complete street but the second could be.

The principal noted that students would feel safe and comfortable when using transit, but the students and their parents would not feel that it is safe and comfortable for walking and biking alone to school because of the busy street the school is on (not Franklin Boulevard), fast traffic, and unsafe young drivers attending the nearby high school. The school has adequate bicycle parking but has a new bike rack that has not been installed. The principal thought that parents would be comfortable if the students walked or biked to school with at least one adult.

As noted, the principal was surveyed because the school was within the biking buffer, but the school is mostly cut off from Franklin Boulevard by the freeway. It is therefore not surprising that the principal did not think that the Franklin Boulevard complete street would improve biking and walking to the school. The principal did note three other streets on the east side of the freeway that if converted to complete streets would improve biking and walking to the school.

Access to Jobs

A similar method used for calculating access to jobs for the San Fernando Street case study was used for the Franklin Boulevard complete street case study. Table 36 presents the results for access to jobs for walking (0.5-mile), biking (2-mile), and transit (polygon buffer) modes before the construction of the complete street.

The expectation for accessibility to jobs after the construction of Franklin Boulevard complete street is that there will be an increase in investments and jobs along the road segment. According to the Franklin Boulevard complete street project design for 2040 prepared by the City of Sacramento and the Department of Public Works (2018), a 62% increase will be seen in the accessibility to jobs (see Table 37). Job retention at current businesses is also a priority of the neighborhood and the complete street treatment is one key strategy for meeting this priority by increasing the viability of the existing businesses.

Table 36. Access to Jobs for Walking (0.5-mile), Biking (2-mile), and Transit (Polygon buffer) Modes in 2019 (before building the CS) for Franklin Case Study

Buffer		Coffee shop	Restaur-ant	Bank	Gas station	Grocery store	Pharm-acy	Hosp-ital	Post office	Library	Police station	Places of Worship	Museum	Govt. Build-ing	Office Build-ing
0.5 miles	**Number of job sites**	3	27	1	5	12	3	0	0	0	1	19	0	0	0
	Accessibility	21	486	7	30	396	60	0	0	0	762	95	0	0	0
2 miles	**Number of job sites**	26	125	18	42	51	22	2	4	7	2	110	1	22	4
	Accessibility	357	4,158	259	228	1,815	440	0	64	135	1,524	315	510	3,470	194
Polygon Buffer	**Number of job sites**	4	44	5	14	20	6	0	0	1	1	33	0	4	0
	Accessibility	28	792	35	84	660	120	0	0	15	762	165	0	1,010	0
Total Accessibility in 0.5-mile buffer= 1,857															
Total Accessibility in 2-mile buffer= 13,469															
Total Accessibility in Polygon buffer= 3,671															

Table 37. Access to Jobs for Walking (0.5-mile), Biking (2-mile), and Transit (Polygon Buffer) Modes- Before versus After the construction of the Franklin Boulevard

Total Accessibility Jobs	Before	After
Total Job Accessibility in 0.5-mile buffer (Walking)	1,857	3,008
Total Job Accessibility in 2-mile buffer (Bicycling)	13,469	21,820
Total Job Accessibility in Polygon buffer (Transit)	3,671	5,947

Job Creation

The same methodology used for calculating job creation for the San Fernando Street case study was used for the Franklin Boulevard complete street case study. SACOG's proposed budget for the construction of the Franklin Boulevard complete street project is around $9.148 million (City of Sacramento and Department of Public Works, 2018). Thus, the total number of jobs associated with the project based on modeling are expected to be:

- $9.148 * 7.61 * 50% = 35 Direct jobs
- $9.148 * 7.61 * 25% = 18 Indirect jobs
- $9.148 * 7.61 * 25% = 17 Induced jobs

This results in a total of 70 jobs estimated to be created by the construction of the Franklin Boulevard complete street project.

As mentioned previously job retention is a key priority, and the Franklin Boulevard plan is intended to help improve the viability of existing locally owned businesses and the jobs they provide. This is particularly important in disadvantaged neighborhoods where loss of existing businesses can contribute to gentrification when outside businesses move into a distressed neighborhood. A metric for business and job retention has not yet been developed for this effect of a complete street.

Connectivity Index

Different routes and options in a 1.6-mile long (the length of the complete street project) rectangular buffer (Figure 23) around Franklin Boulevard between 12th Avenue and 38th Avenue were calculated. As shown in Figure 24, three circles with a 1.6-mile diameter were drawn in the center and edges of the Franklin Boulevard complete street, which made a 3.2 by 1.6 square miles rectangle. The area of this rectangle was then measured to calculate the connectivity index via Google Earth and Google Maps.

Figure 23. Considered area for measuring the Connectivity Index, Franklin Boulevard Case Study

Table 38 shows the description and calculations for the selected indices considered for connectivity for Franklin Boulevard Since the northern part of Franklin Boulevard has a lower socio-economic score compared to the southern part, Table 38 presents the connectivity for these two parts separately and as well as together.

According to the Franklin Boulevard complete street project design for 2040 published by SACOG in 2018 (City of Sacramento and the Department of Public Works, 2018), the number of 3 and 4-leg intersections will increase by about 13%, which results in an increase in the connectivity index performance measure in Franklin Boulevard complete street project.

Table 38. Connectivity Results for Franklin Boulevard Case Study Based on the Selected Connectivity Indices

Measure	**Definition and Calculation**	**Notes**		**Before the complete street construction**	**After the complete street construction**
Intersection Density	Number of intersections in a given land area, such as a square mile or acre.	Limited to "3 and 4-leg intersections", Typical Range For "Good" Connectivity: 100-160 (Harvey et al., 208, adapted from Semler et al., 2016)	South part of Franklin Boulevard	245/ (3.2*1.6)= **48**	
			North part of Franklin Boulevard	486/ (3.2*1.6)= **95**	
			Total	**145**	**164**
Intersections per Linear Mile	Number of intersections in a given land area is divided by the linear network miles in the same area.	Limited to "3 and 4-leg intersections" (Harvey et al., 208, adapted from Semler et al., 2016)	South part of Franklin Boulevard	245/3.2/ (3.2*1.6) = **15**	
			North part of Franklin Boulevard	486/3.2/ (3.2*1.6) = **30**	
			Total	**45**	**51**

Active Transportation to Local and Regional Transit Connectivity Index

Aerial imagery, Google Earth, and a static map were used to calculate this measure by selecting all the bikeway/walking path segments within a 1.6-mile buffer of regionally significant transit stations. The total bikeway miles within the buffer were then divided by land area within the buffer (see Figure 24). The 3.2*1.6 square mile rectangle buffer around the transit station at the intersection of Fruitridge Road and Franklin Boulevard was considered a network area; the location of the station is almost at the center of the Franklin Boulevard complete street. Table 39 depicts the results for the active transportation transit connectivity index for Franklin Boulevard complete street.

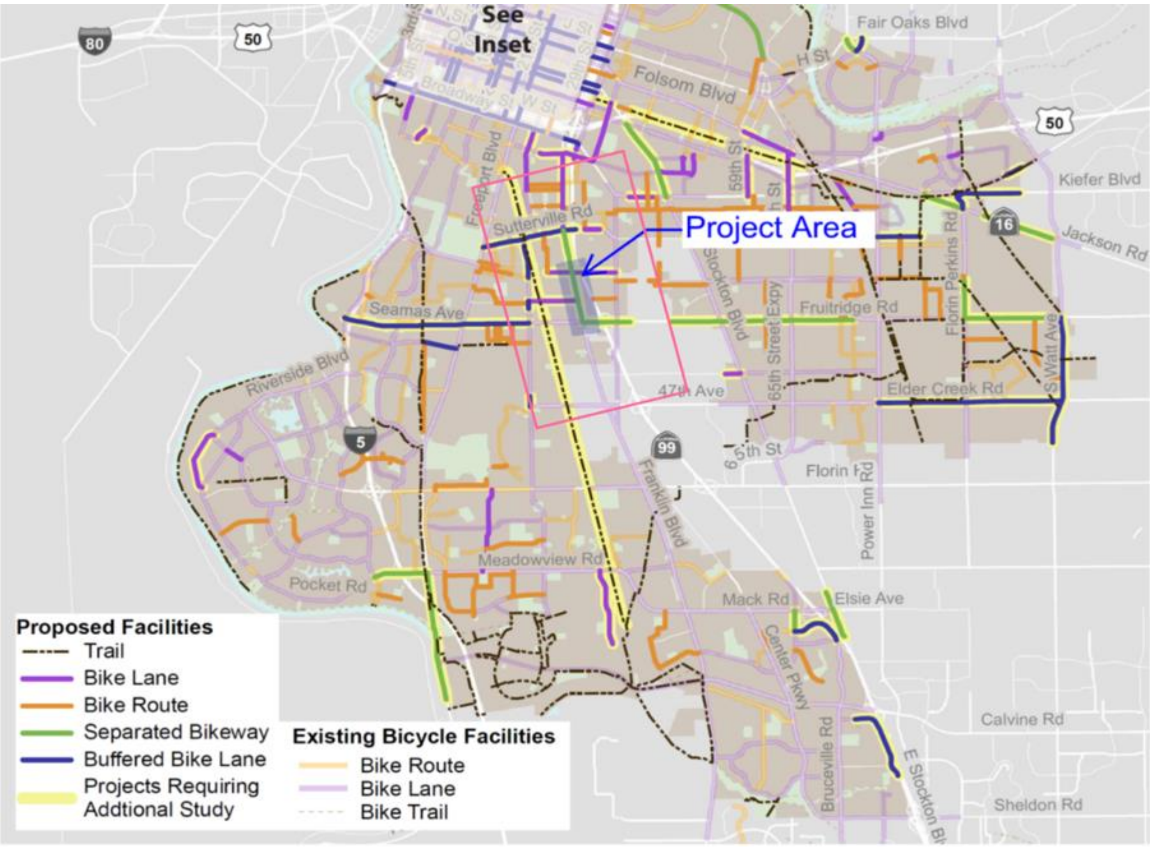


Figure 24. Bike network around Franklin Boulevard derived from Project Performance Assessment (PPA) Tool (SACOG, 2020, and City of Sacramento and Department of Public Works, 2018)

Table 39. Results for the Active Transportation Transit Connectivity Index for Franklin Boulevard Complete Street Project

Measurement	Current conditions (no complete street build)	Expected outcome (after the complete street is build)
Mileage of bike/ ped. Lane (2-side)	**15.6** mile	**40.2**
Bike/ ped facility density (2-side)	7.8/(3.2*1.6)= **3**	**7.8**

Pedestrian and Bicyclist Delay

Dunn and Pretty's equations (Dunn and Pretty, 1984; FHWA, 1998) mentioned in the section of Performance Measures Considered in Complete Street Case Studies were used to calculate pedestrian delay at signalized pedestrian crossings for the Franklin Boulevard case study. Dunn and Pretty's equations and the FHWA guidance were also used to calculate the green interval duration. Calculations for the total delays in a rectangular buffer (1.6-mile*3.2-mile) around the Franklin Boulevard case study are presented in Table 40 and Table 41.

This indicator was calculated for the year 2019 since the complete street project had not been built yet, using Google Earth™ and Google Earth historical imagery features. According to these tools and the Sacramento County general plan (Sacramento County General Plan, 2020), there will be a small difference (13% increase in the number of intersections) between before (2019) and after (2040) the construction of the Franklin Boulevard complete street project. Calculations for the total delays in a rectangular buffer (1.6-mile*3.2-mile) around the Franklin Boulevard complete street before building the complete street and after the construction of this project are presented in Table 40 and Table 41, respectively.

Table 40. Total delays in a rectangular buffer (1.3-mile*2.6-mile) around the Franklin Boulevard case study- Before the Complete Street Construction

g: vehicular green signalFormula	**d: Average delay (s) for narrow roadway (Minor arterial)** $d = \frac{(g+15)^2}{2\,(g+20)}$	**d: Average delay (s) for narrow roadway (Major arterial)** $d = \frac{(g+10)^2}{2\,(g+15)}$	**No. of arterial within 1.6-mile* 3.2-mile buffer (Minor Arterial)**	**No. of arterial within 1.6-mile* 3.2-mile buffer (Major Arterial)**	**Total delay(s) for Minor arterial**	**Total delay(s) for Major arterial**	**Total delay(s) in 1.6mile* 3.2mile buffer**
minimum green interval duration: Minor arterial: 4-10 s (avg 7 s) Major arterial: 7-15 s (avg 11 s)	d= [(7+15)^2]/ [2*(7+20)]= **9 s**	d= [(11+10)^2]/ [2*(11+15)]= **8.5**	208	6	1872	51	**1923**
maximum green interval duration: Minor arterial: 40-50 s (avg 40 s) Major arterial: 40-60 s (avg 50 s)	d= [(40+15)^2]/ [2*(40+20)]= 25.2~ **25 s**	d= [(50+10)^2]/ [2*(50+15)]= 27.7 ~ **28**	208	6	5200	168	**5368**
Average Delay					3536	109	**3645 (61min)**

Table 41. Expected total delays in a rectangular buffer (1.3-mile*2.6-mile) around the Franklin Boulevard case study- After the Complete Street Construction

g: vehicular green signal Formula	**d: Average delay (s) for narrow roadway (Minor arterial)** $d = \frac{(g+15)^2}{2\,(g+20)}$	**d: Average delay (s) for narrow roadway (Major arterial)** $d = \frac{(g+10)^2}{2\,(g+15)}$	**No. of arterial within 1.6-mile* 3.2-mile buffer (Minor Arterial)**	**No. of arterial within 1.6-mile* 3.2-mile buffer (Major Arterial)**	**Total delay(s) for Minor arterial**	**Total delay(s) for Major arterial**	**Total delay(s) in 1.6mile* 3.2mile buffer**
minimum green interval duration: Minor arterial: 4-10 s (avg 7 s) Major arterial: 7-15 s (avg 11 s)	d= [(7+15)^2]/ [2*(7+20)]= **9 s**	d= [(11+10)^2]/ [2*(11+15)]= **8.5**	235	7	1998	61	**2059**
maximum green interval duration: Minor arterial: 40-50 s (avg 40 s) Major arterial: 40-60 s (avg 50 s)	d= [(40+15)^2]/ [2*(40+20)]= 25.2~ **25 s**	d= [(50+10)^2]/ [2*(50+15)]= 27.7 ~ **28**	235	7	5876	190	**6066**
Average Delay					3536	125	**4062 (68min)**

Level of Service

PLOS and BLOS

The HCM methodology was tested, and required data were found for the Link PLOS, Segment PLOS, and Pedestrian Space LOS. However, the Intersection PLOS could not be calculated due to data unavailability. Segment PLOS is equivalent to the link PLOS in the HCM methodology. The HCM Link PLOS methodology is used to get a letter grade for link PLOS. The HCM Pedestrian Space methodology is followed to get a letter grade for the facility PLOS.

Unavailable traffic data was the main problem in calculating PLOS and BLOS in the Franklin Boulevard case study making before-and-after LOS comparison difficult. Data on ADT was acquired from the planning documents of Franklin Boulevard (City of Sacramento Department of Public Works, 2018). Table 42 to Table 46 shows the PLOS and BLOS results for the Franklin Boulevard case study.

Table 42. NCHRP Link PLOS for Franklin Complete Street

Methodology	Before complete street was built	After complete street was built
Link PLOS Score	2.54	0.15

Due to traffic data unavailability, after the complete street was built, it is difficult to predict how Link PLOS changed (see Table 42). As mentioned before, a lower number indicates better quality of services. A letter grade cannot be assigned to the NCHRP Link PLOS value because the letter LOS grade applies only to the full facility score and not to the link score.

Table 43. Segment-Based LOS by Average Pedestrian Space for Franklin Boulevard Complete Street

Methodology	Before complete street was built	After complete street was built
Segment-Based LOS by Average Pedestrian Space	A (2006)	A (2408)

The sidewalks in many parts of Franklin Boulevard prior to the complete street were generally narrow, with electrical poles and numerous driveway cutouts on the sidewalks creating unsafe conditions for pedestrians, particularly those in wheelchairs or walking with children or strollers. The sidewalks will be widened after the expected construction of the Franklin Boulevard complete street. The PLOS methodology did not provide much recognition to these changes regarding the space and particularly the quality of the space, as can be seen in Table 43 (A: best, and F: worst quality of service, and lower number indicates better quality of services).

Table 44. HCM Link PLOS for Franklin Boulevard Complete Street

	Before complete street was built		**After complete street was built**	
HCM Link PLOS	NB	SB	NB	SB
	D	E	B	B
	D (4.24)		B (2.2)	

**NB: North Bound, and SB: South Bound*

As shown in Table 44, HCM Pedestrian link LOS score was D (average of northbound and southbound) before the complete street was built and is assigned B after the complete street is built. This significant improvement is because of the new bike lane and parking buffer and the expanded sidewalk. It should be noted that, since the current framework does not consider the accessibility of sidewalks for ADA and this was very important for Franklin Boulevard, adding consideration of accessibility for disabled people to the BLOS performance measure will be valuable.

The HCM intersection BLOS was not calculated due to a lack of data. The NCHRP methodology, which is not very data-intensive, was used to calculate link BLOS, as presented in Table 46.

Table 45. HCM Link BLOS Before and After Construction of Franklin Boulevard Complete Street

	Before complete street was built		**After complete street was built**	
Link BLOS	NB	SB	NB	SB
	C	D	A	A
	D (3.73)		A (1.44)	

**NB: North Bound, and SB: South Bound*

Table 46. NCHRP Link BLOS Before and After the Construction of Franklin Boulevard Complete Street

	Before complete street was built		**After complete street was built**	
Link BLOS	NB	SB	NB	SB
	D	D	D	D
	D (3.69)		D (3.98)	

**NB: North Bound, and SB: South Bound*

HCM Link BLOS, as can be seen in Table 45, gives realistic results before and after the complete street construction. The constant score of BLOS before and after the construction of the complete street indicates that the NCHRP BLOS methodology is not appropriate for Class IV bike lanes since this methodology's equations and parameters do not match up well. For instance, the width of paving between the outside lane stripe and the edge of the pavement is the shoulder of the road for a Class II bike lane. If there is no shoulder and a barrier with a bike lane on the other side, the input distance is unclear.

The inflexibility of the NCHRP BLOS equations limits the applicability of this model and is not recommended for use on the Franklin Boulevard case study. Use of the HCM Link BLOS performance measure is recommended. The level of Traffic Stress (LTS) indicator is also recommended to be used as a more qualitative measure of bicycle comfort.

Urban LOS

According to the FHWA Traffic Data Pocket Guide (FHWA, 2018), the hourly design volume should be around 8% of the average daily traffic (ADT). This amount is larger than the amount of ADT divided by 24 hours (4.16%). ADT for Franklin Boulevard is 12,960 and 11,016 before and after the complete street was built, respectively (City of Sacramento, 2020b). Hourly traffic volume data are needed to calculate Urban LOS, which can be calculated by multiplying the ADT by 8%. The result is 1,039 (12,960 ADT*8%=1,037) vehicles per hour before the complete street was built and 881 (11016 ADT*8%=881) vehicles per hour after the complete street was built.

Due to a lack of signal timing data and detailed traffic movement data, the intersection LOS could not be calculated. Since there are only four traffic signals in the Franklin Blvd case study, the traffic congestion along this boulevard will not be changed much by signal timing changes. Table 47 presents the urban streets level of service for before and after the construction of Franklin Boulevard complete street.

Table 47. Urban Streets Level of Service for Before and After the Construction of Franklin Boulevard Complete Street

Segment	Travel Speed (mph)	LOS	Segment Length (feet)	BFFS*
Urban Streets LOS BEFORE Construction				
12th-21st	31.2	B	2,752	40.1
21st-26th	16.8	D	1,828	38.6
26th-Fruitridge	28.3	B	1,418	37.7
Fruitridge-38th	33.4	A	2,490	40.7
Weighted Average	**28.2**	**B**	**-**	**39.6**
Urban Streets LOS AFTER Construction				
12th-21st	24.2	B	2,752	35.99
21st-26th	22.7	C	1,828	37.54
26th-Fruitridge	22.9	C	1,418	37.83
Fruitridge-38th	28.6	B	1,418	39.92
Weighted Average	**24.4**	**C**	**-**	**37.48**

**BFFS is Base Free Flow Speed*

Urban LOS is scored based on how fast traffic moves compared to the BFFS

Transit LOS

The HCM methodology (HCM, 2016) and the Transit LOS Calculator (TCRP) were used to calculate TLOS in Franklin Boulevard (TRB, 2013).

Transit LOS for before the construction of the Franklin Boulevard complete street was calculated as LOS D, which is served by one bus route. The Northbound (NB) direction includes four bus stops, while three bus stops are in the Southbound (SB) direction. Since only one bus route serves Franklin Boulevard (Sac RT Route 67), and one-fifth of the residents do not have access to a car (MIG INC., 2019). An in-depth traffic analysis would be helpful to determine exactly how bus delays will be affected by the complete street project after the construction. Table 48 presents the TLOS for segments with transit service, and Table 49 shows the entire facility TLOS before and after the construction of Franklin complete street. Note that the construction of Franklin Boulevard has not been completed yet.

Table 48. Transit LOS Segments with Transit Service Before and After Construction for the Franklin Boulevard Complete Street

	Before complete street was built		**After complete street was built**	
Transit LOS for the Segment	NB	SB	NB	SB
	C	D	C	C
Average Transit LOS for the Segment	**D**		**C**	

Table 49. Transit LOS Entire Facility Before and After the Construction of Franklin complete street

Segment	**Score**	**LOS**	**Segment Length (feet)**
Transit Streets LOS BEFORE Construction			
12th Street to 21st Street	3.69	D	2752
21st to 38th	4.26	D	5755
Weighted Average Score	**5.68**		
Weighted average LOS		**F**	
Transit Streets LOS AFTER Construction			
12th Street to 21st Street	3.02	C	2752
21st to 38th	6.35	F	5755
Weighted Average Score	**5.27**		
Weighted average LOS		**F**	

Franklin Boulevard lies between State Route 99, the Union Pacific Railroad, and it does not have parallel streets to redirect buses into them. There is no plan to expand the bus services after the construction of the complete street. However, to serve the Franklin Boulevard community, a new on-demand shuttle service (SmaRT) was implemented by Sac RT in 2018. Using a mobile app or making phone calls can be used by the riders to schedule a pick-up at a nearby bus stop followed by departing at a drop-off location near their choice of destination. In July 2020, and despite COVID 19 impacts on public transit, more than 12,000 rides were provided by SmaRT Ride (SacRT 2020). Since the value of the SmaRT Ride shuttle service cannot be expressed in terms of LOS, expanding the performance measure, including other metrics such as transit ridership, would be useful. It is not expected that the 12,000 rides carried on the shuttle will include many riders from Franklin to the light rail station. It was outside the ability of this study to consider this additional transit connection.

The combination of Franklin Boulevard complete street with projects that aim to improve transit service in the community will lead to the TLOS improvements.

Level of Traffic Stress (LTS)

The Montgomery County Bicycle Master Plan (2018) cannot be used to measure the LTS for Franklin Boulevard due to the absence of bike lanes. Instead, the LTS tables derived from Northeastern University are used for measuring Franklin Boulevard LTS (Furth, 2017) and are presented in Appendix D.

According to the Northeastern University tables, the LTS for Franklin Boulevard is usually between 3 and 4. There is a bike lane from 38th Avenue to 35th Avenue based on the report by the City of Sacramento and the Department of Public Works in 2018. There are no bike lanes from 35th Avenue to 32nd Avenue, from Fruitridge Road to Sutterville Rd. on the west side, and from 34th Avenue to Sutterville Rd. on the east side. The following definitions are derived from the Northeastern University study,

- No bike lane: mixed traffic
    - LTS = 4
- A bike lane with no parking
    - LTS ≥ 3
- Intersection LTS
    - LTS = 4
- Unsignalized crossings:
    - LTS = 3

According to the LTS criteria tables in the Northeastern University study, shown in Appendix D of this report, LTS improves from 4 to 1 after the completion of the Franklin Boulevard complete street (see Table 50). LTS score of 1 indicates very low traffic stress, which is suitable for most vulnerable groups.

Table 50. Level of Traffic Stress (LTS) Scores Comparing Before and After Building the Franklin Boulevard Complete Street

LTS Method	Before complete street was built	After complete street was built
Northeastern University Method	**4 (High)**	**1 (Very Low)**

Crashes

For the Franklin Boulevard complete street project, the number of bicycle-involved and pedestrian-involved crashes (i.e., Skateboard, non-motorized scooter, wheelchair crashes) over five years were considered. The Transportation Injury Mapping System (TIMS) database 2015-

2019 was used for this measurement (TIMS, 2020). The 1.6-mile buffer area around the Franklin Boulevard case study was considered for calculating this indicator.

Table 51. Number of Crashes in the 1.3-mile buffer areas around Franklin case study

Years	Number of Crashes	Before the CS= Average (2015-2019) = (20+30+12+11+15)/5 = **18**
2015	20	
2016	30	
2017	12	
2018	11	
2019	15	After the CS = **-**

Table 51 presents the crash performance measure before the construction of Franklin Boulevard complete street. As the complete street has not been built yet, therefore, the indicator cannot be calculated.

Pedestrian Miles Traveled / Bicycle Miles Traveled

The Franklin Boulevard Complete Street Phase 2 report (City of Sacramento and Department of Public Works, 2018) was used to find data for this performance measure. According to this report, there were 444 pedestrians and 170 bicyclists per day using Franklin Boulevard in 2018. PMT and BMT are calculated for average trip lengths of 0.5 miles and 2 miles. As the complete street project is not completed yet, therefore, the Sacramento County design documents were used to find the number of bike and pedestrian trips. Based on the general plan 2035, bike mode share and pedestrian mode share are expected to increase by 1.8% and 12.4%, respectively (City of Sacramento and Department of Public Works, 2018). Table 52 presents PMT and BMT for average trip lengths of 0.5 miles and 2 miles. Increases in PMT and BMT are expected after the construction of the Franklin Boulevard complete street.

Table 52. Pedestrian Miles Traveled, and Bicycle Miles Traveled for Franklin Boulevard Case Study

Year	Trip Length	PMT	BMT
Before complete street is built (2018)	0.5 miles	222	85
	2 miles	888	340
After complete street is built (2035)	0.5 miles	1,433	261
	2 miles	5,732	1,044

Street Trees

The number of trees was counted along Franklin Boulevard from 12th Avenue to 38th Avenue. The grant application for the SACOG Regional Active Transportation Program was used to count the street trees after the complete streets project (City of Sacramento and Department of Public Works, 2018).

Table 53. Number of Street Trees along the Franklin Boulevard Complete Street

Year	Number of street trees
Current count from 2018	49
Expected in 2040 (after building the complete street)	349

As can be observed from Table 53, the number of street trees will be increased to meet a complete streets goal for improving livability and safety.

The addition of street trees is likely to increase carbon sequestration in the trees, change human thermal comfort cause by the shade, and have an effect on the overall urban heat island. At this time there is no methodology for calculating change in GWP or human thermal comfort, and no simple way to calculate the change in urban heat island. Development of these indicators would add value to the Street Trees indicator.

Kentucky Avenue Case Study

Access to Community Destination

For the complete street case study, destinations within 0.5-mile walking and 2-mile bicycling radii of Kentucky Avenue were found using Google Earth ™ and Google Maps™ (see Figure 25). The average walking speed is assumed to be three mph, while the bicycling speed is assumed to be 12 mph (Yang and Diez-Roux, 2012). The average walking distance is 0.5 miles, while the average bicycling distance is 2 miles, considering delay.

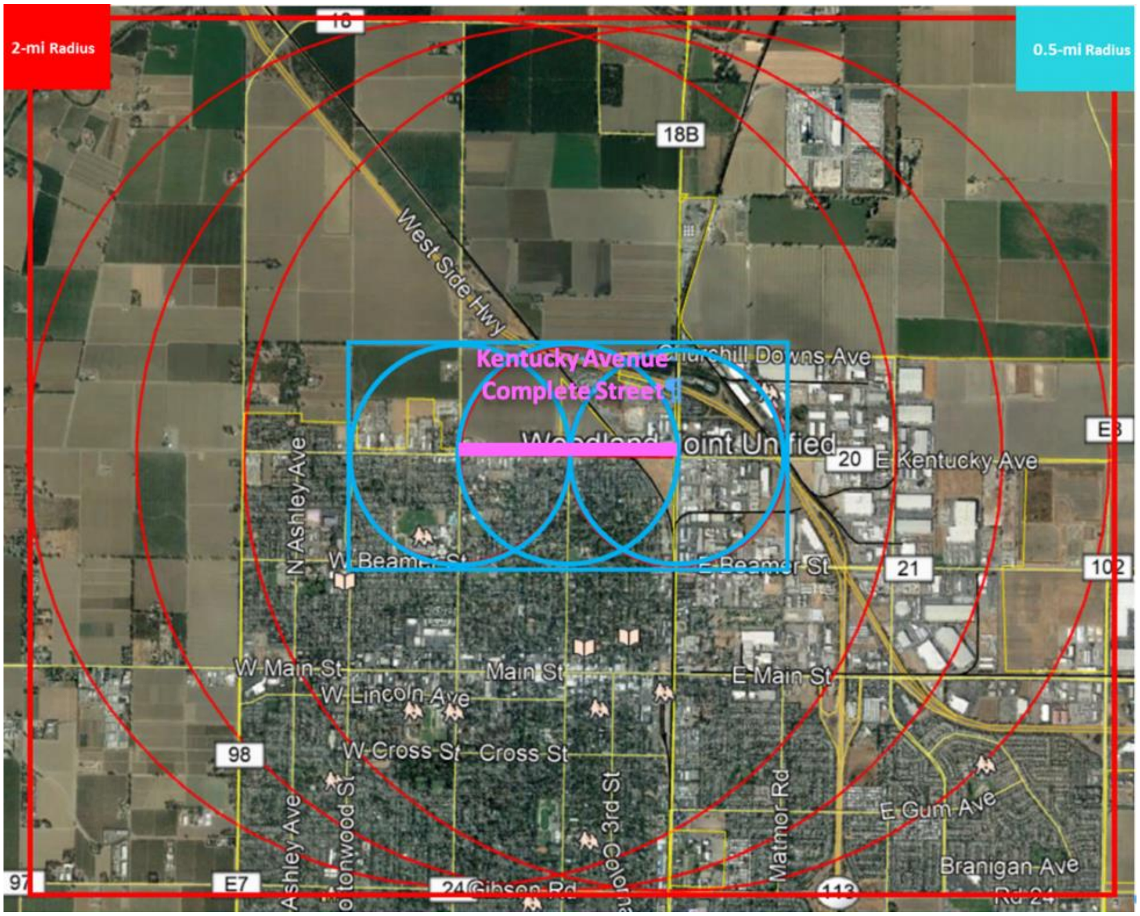


Figure 25. Access to Destination Buffer Area for Walking and Cycling Modes of Transportation, Kentucky Avenue Complete Street Project

To consider the transit buffer area around the Kentucky Avenue complete street, there are many possibilities when combining walking and biking with train, bus, and light rail. According to Yang and Diez-Roux's study (2012), there is considerable variability in the distance and duration of walking trips by purpose and population subgroups. The most probable scenarios were selected considering 20 minutes for a combined-mode trip.

A circular buffer was the first option considered around the Kentucky Avenue complete street. However, due to geographical barriers and the limited number of transit stations, especially in the northern and western parts around this project's area, the circular buffer was not used. The proposed alternative buffer can be seen in Figure 26. As shown in the figure, the right side of the buffer includes a 0.5-mile buffer around Kentucky Avenue. The buffer extends 2 miles south along Ashley Ave and extends 0.5-mile to the East and 0.5 miles to the west of the complete street. The center part of this buffer contains several bus stops, as the map shows (Figure 27).

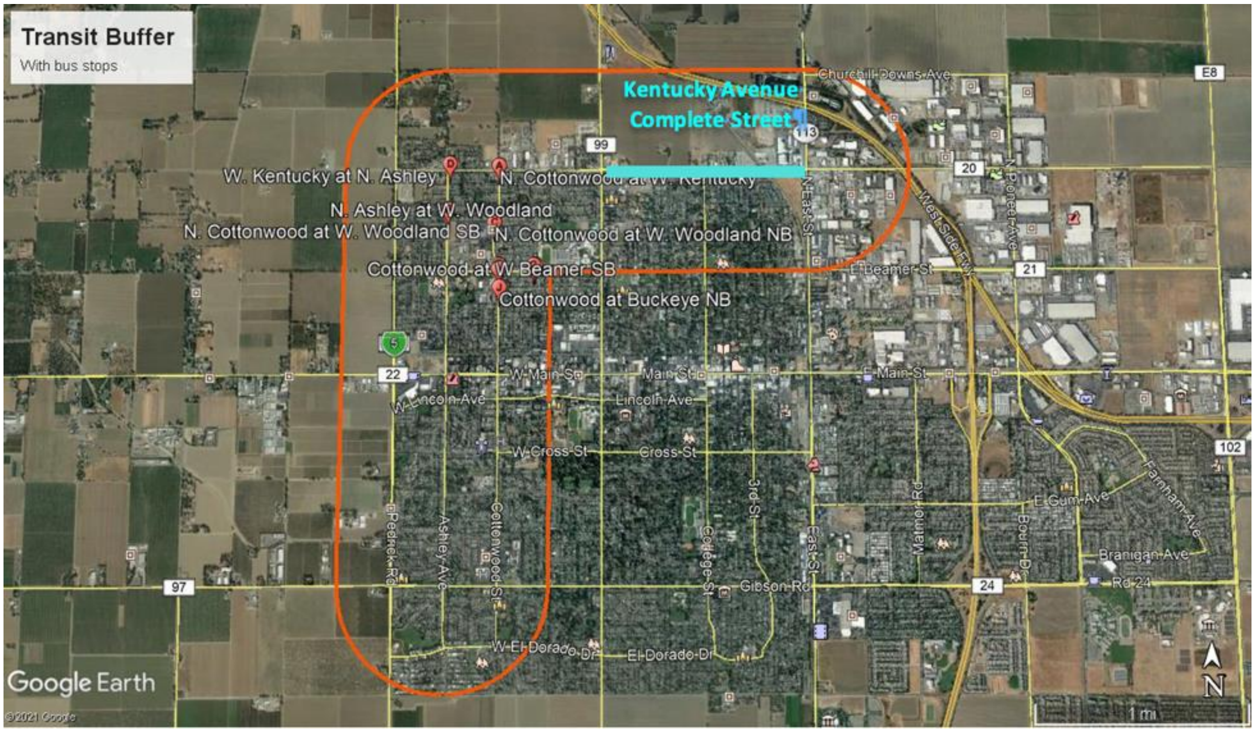


Figure 26. Access to Destination Buffer Area for Transit Modes of Transportation, Kentucky Complete Street Project

Table 54 shows the recommended buffer distances using in different modes of transportation in 20 minutes.

Table 54. The Recommended Buffer Distances Using in Different Modes of Transportation in 20 minutes

Recommended Buffer Distance	Mode
0.5 mile (Figure 26)	Walking
2 mile (Figure 26)	Biking
Transit Buffer Area (Figure 27)	Bus+Walking, Bus+Biking

The destinations considered in this case study include coffee shops, restaurants, banks, gas stations, grocery stores, pharmacies, hospitals, post offices, libraries, police stations, places of worship, and museums. The number of customers and employees for each destination was estimated using the best available resources, including government statistics, company information, and web research (see Appendix B). Access to community destinations calculations can be found in Appendix B**.**

The example calculations were shown earlier in the San Fernando complete street case study. Table 55 shows the example of access to community destinations in a 0.5-mile circular buffer for Kentucky Avenue in 2018. Table 56 and Table 57 present this performance measure for walking (0.5-mile), biking (2-mile), and transit (polygon buffer) modes before (2018) and after (2021) the construction of the Kentucky Avenue complete street.

Table 55. Access to Community Destinations in a 0.5-mile Circular Buffer for Kentucky Avenue in 2018

Destination category	Coffee shop	Restaurant	Bank	Gas station	Grocery store	Pharmacy	Hospital	Post office	Libraries	Police station	Places of Worship	Museum
Number of destinations in 0.5-mile buffer	0	5	0	3	5	0	0	0	0	0	6	0
Estimated employees	7	18	7	6	33	20	100	16	15	762	5	30
Estimated customers	350	230	42	682	853	350	225	71	682	100	27	273
Employee accessibility	0	90	0	18	165	0	0	0	0	0	30	0
Customer accessibility	0	1,150	0	2,046	4,265	0	0	0	0	0	162	0
Total Accessibility: 0.5-mile buffer	0	1,240	0	2,064	4,430	0	0	0	0	0	192	0
Total Accessibility in 0.5-mile buffer= 7,926												

Example: Total Accessibility in 0.5-mile Buffer = 5(18+230) = 1240*

As observed from Table 56, Table 57, and Table 58, access to destinations along Kentucky Avenue decreased in most destinations, stayed the same in some of them, and increased in a few destinations from 2018 to 2021. Thus, the changes in the typology of the complete street that required demolishing several of the buildings around the street, can be justified by the changes in the typology of the complete street.

Table 56. Access to Community Destinations for Walking (0.5-mile), Biking (2-mile), and Transit (Polygon Buffer) Modes in 2018 (before building the CS) for Kentucky Avenue

Buffer		**Coffee shop**	**Restaur-ant**	**Bank**	**Gas station**	**Grocery store**	**Pharmacy**	**Hospital**	**Post office**	**Library**	**Police station**	**Places of Worship**	**Museum**
0.5	Number of destinations	0	5	0	3	5	0	0	0	0	0	6	0
	Total Accessibility:	0	1,240	0	2,064	4,430	0	0	0	0	0	192	0
2	Number of destinations	7	89	9	18	29	13	2	2	4	1	33	5
	Total Accessibility:	2,499	22,072	441	12,384	25,694	4,810	650	174	2,788	862	1,056	1,515
Transit Buffer	Number of destinations	2	19	2	5	9	4	2	1	1	0	13	0
	Total Accessibility:	714	4,712	98	3,440	7,974	1,480	650	87	697	-	416	-
Total Accessibility in 0.5-mile buffer= 7,926													
Total Accessibility in 2-mile buffer= 74,945													
Total Accessibility in Transit buffer= 20,268													

Table 57. Access to Community Destinations for Walking (0.5-mile), Biking (2-mile), and Transit (Polygon Buffer) Modes in 2021 (after building the CS) for Kentucky Avenue

Buffer		Coffee shop	Restaur-ant	Bank	Gas station	Grocery store	Pharmacy	Hospital	Post office	Library	Police station	Places of Worship	Museum
0.5	Number of destinations	0	5	0	3	5	0	0	0	0	0	6	0
	Total Accessibility:	0	1,240	0	2,064	4,430	0	0	0	0	0	192	0
2	Number of destinations	5	90	11	21	25	10	2	2	3	1	32	5
	Total Accessibility:	1,785	22,320	539	14,448	22,150	3,700	650	174	2,091	862	1,024	1,515
Transit Buffer	Number of destinations	2	21	2	5	9	3	2	1	1	0	14	0
	Total Accessibility:	714	5,208	98	3,440	7,974	1,110	650	87	697	-	448	-
Total Accessibility in 0.5-mile buffer= 7,926													
Total Accessibility in 2-mile buffer= 71,258													
Total Accessibility in Transit buffer= 20,4260													

Table 58. Access to Community Destinations for Walking (0.5-mile), Biking (2-mile), and Transit (Polygon buffer) Transport Modes-Before the construction versus After the construction of the Kentucky Avenue Complete Street Project

Total Accessibility to community Destinations	Before	After
Total Accessibility in 0.5-mile buffer (Walking)	7,926	7,926
Total Accessibility in 2-mile buffer (Bicycling)	74,945	71,258
Total Accessibility in Transit buffer (Transit)	20,268	20,426

Access to School

School district boundaries around the Kentucky Avenue complete street are shown in Figure 27.

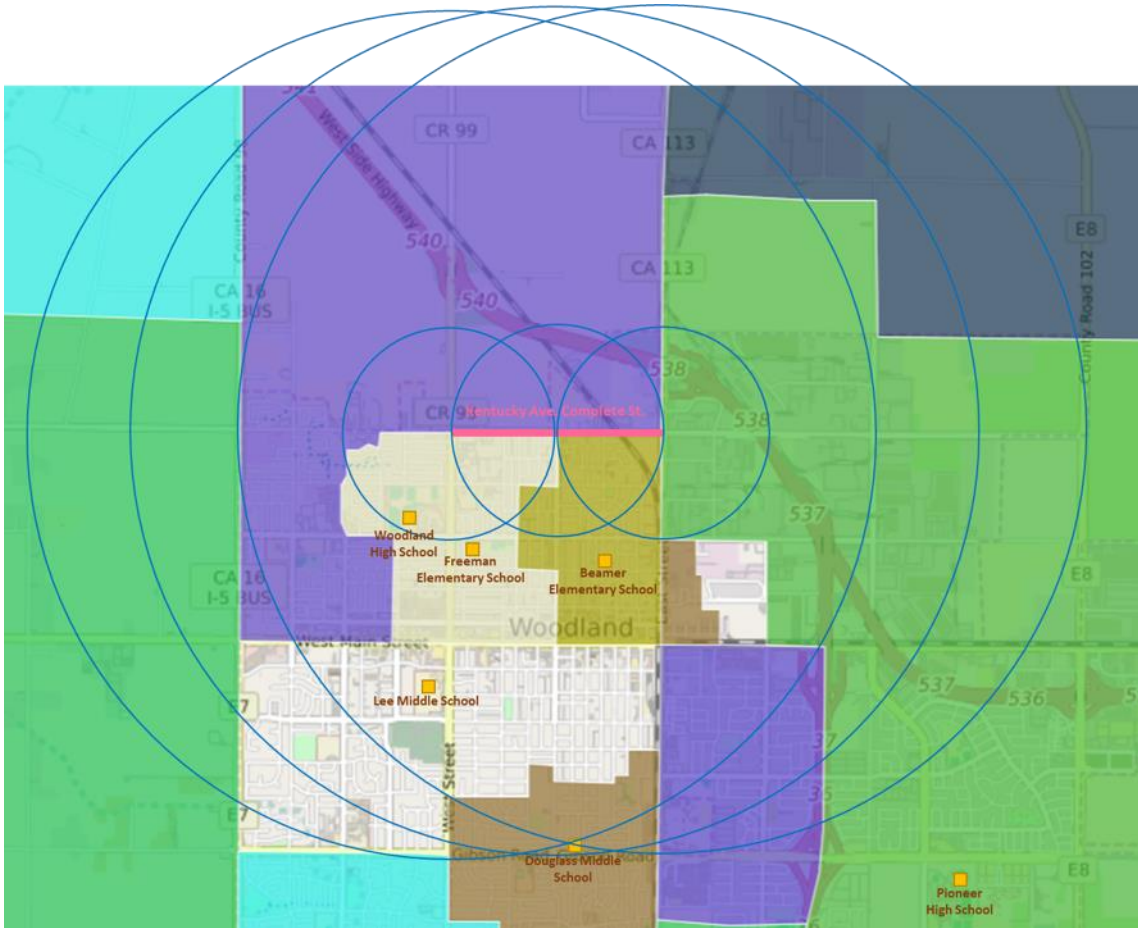


Figure 27. Access to School (considering school district boundaries)- Kentucky Avenue Case Study

Table 59 presents the access to school results according to school district boundaries within walking (0.5-mile) and bicycling (2-mile) distances. The complete list of schools, number of students, and employees for the Kentucky Avenue case study can be found in Appendix C.

Table 59. Accessibility to School considering school district boundary for each buffer, Kentucky Avenue Case Study.

Distance	Accessibility
0.5-mile (Walking)	1,285
2-mile (Cycling)	5,361

The Access to School indicator for both before building the complete street (2018) and after building the complete street (2021) is the same due to no change in the number of schools between these two years.

The area long the Kentucky Avenue complete street does not have schools close to it. Transit can be included in those destination development projects to provide active transportation access. While it is not known how many students live within the bicycling and walking buffers for Kentucky Avenue, having nearby schools is more important for disadvantaged neighborhoods such as Kentucky Avenue because they tend to have fewer transportation alternatives.

Surveys of Principals

Access to school surveys were sent to the principals of six schools in the Kentucky Avenue study area based on the boundary discussed earlier above. One was returned from a middle school. As was noted for the other two case studies, the survey was sent out at the beginning of summer in 2020 and again later in the summer. The extra work being undertaken by principals at that time to deal with changing Covid protocols and the return to in-person teaching makes the lack of response understandable. The one response to the survey to the survey provides useful qualitative and quantitative answers from the principal who responded and suggests that further use of the survey instrument in future research will provide important information that cannot be obtained otherwise.

The principal noted that Kentucky Avenue is “quite a ways from out campus” but said that some students and their parents may use the street to get to the school. The principal estimated that 25 to 45% of students walked, depending on the season (most in fall and spring, least in winter), 10 to 15% biked, 10% took transit, and 30 to 55% were driven, bike and car travel mirroring the seasonal differences of walking. A travel pattern that was not considered when putting the survey together is that the principal estimated that many students are travel by car in the morning and walk home in the afternoon. The principal also noted that the transit use is by district school bus and represents students being bussed in from a neighboring town that is in the district. The principal estimated that these percentages did not change with the completion of the Kentucky Avenue complete street.

The travel times for students to commute to school are shown in Table 60.

Table 60. Estimated commute times by mode

Time	Walk (6th to 8th grade)	Bike (6th to 8th grade)	Bus/Train (6th to 8th grade)	Car (6th to 8th grade)	Combination trip (6th to 8th grade)	Other
0-10 minutes	5-10%	10%		30%		
10-20 minutes	20%	5%		10%		
20-30 minutes	5%		10%	5%		
30-40 minutes						

The estimated percentages of students traveling to school without an adult are shown in Table 61.

Table 61. Estimated percentages of students biking or walking alone by grade.

Grade	6th	7th	8th
Percentage Biking		10-15%	10-15%
Percentage Walking		45%	45%

The principal identified that those students using active transportation mostly do not use Kentucky Avenue. The principal thought that the complete street would make Kentucky Avenue safer for those students who use it. The principal noted four other streets nearer to the school that would benefit from a complete streets treatment. The school has bike racks. The principal thought that students generally feel safe walking and biking with or without an adult, although it was noted that there is speeding traffic around the school, and that students oftentimes do not wear helmets and engage in risky behavior on bicycles.

Overall, the principal did not think that the Kentucky Avenue complete street would improve biking and walking to the school except for the few students who may come from the neighborhood near it and identified another arterial street much closer to the school that students use.

Access to Jobs

A similar method used for calculating access to jobs for the San Fernando case study was used for the Kentucky Avenue complete street case study. Table 62 and Table 63 present the results for access to jobs for walking (0.5-mile), biking (2-mile), and transit modes before and after the construction of Kentucky Avenue complete street.

As can be observed from Table 64, there is a decrease in accessibility to jobs after constructing the complete street within walking and cycling distances which is the result of changes in the typology of the Kentucky Avenue complete street that required demolishing several buildings located on this street.

Table 62. Access to Jobs for Walking (0.5-mile), Biking (2-mile), and Transit (3-mile and 4.5-mile) Modes in 2015 (before building the CS) for Kentucky Avenue

Buffer		Coffee shop	Restaurant	Bank	Gas station	Grocery store	Pharmacy	Hospital	Post office	Library	Police station	Places of Worship	Museum	Govt. Building	Office Building
0.5 miles	**Number of job sites**	0	5	0	3	5	0	0	0	0	0	6	0	1	3
	Accessibility	0	90	0	18	165	0	0	0	0	0	30	0	114	88
2 miles	**Number of job sites**	5	90	11	21	25	10	2	2	3	1	32	5	19	17
	Accessibility	35	1,620	77	126	825	200	200	32	45	762	160	150	872	338
Transit Buffer	**Number of job sites**	2	21	2	5	9	3	2	1	1	-	14	-	8	6
	Accessibility	14	378	14	30	297	60	200	16	15	-	70	-	486	137
Total Accessibility in 0.5-mile buffer= 505															
Total Accessibility in 2-mile buffer= 5,618															
Total Accessibility in transit buffer= 1,696															

Table 63. Access to Jobs for Walking (0.5-mile), Biking (2-mile), and Transit (3-mile and 4.5-mile) Modes in 2019 (after building the CS) for Kentucky Avenue

Buffer		Coffee shop	Restaurant	Bank	Gas station	Grocery store	Pharmacy	Hospital	Post office	Library	Police station	Places of Worship	Museum	Govt. Building	Office Building
0.5 miles	Number of job sites	0	5	0	3	5	0	0	0	0	0	6	0	1	3
	Accessibility	0	90	0	18	165	0	0	0	0	0	30	0	114	88
2 miles	Number of job sites	5	90	11	21	25	10	2	2	3	1	32	5	19	17
	Accessibility	35	1,620	77	126	825	200	200	32	45	762	160	150	872	338
Transit Buffer	Number of job sites	2	21	2	5	9	3	2	1	1	-	14	-	8	6
	Accessibility	14	378	14	30	297	60	200	16	15	-	70	-	486	137
Total Accessibility in 0.5-mile buffer= 505															
Total Accessibility in 2-mile buffer= 5,442															
Total Accessibility in transit buffer= 1,717															

Table 64. Access to Jobs for Walking (0.5-mile), Biking (2-mile), and Transit (Polygon Buffer) Modes- Before versus After the construction of the Kentucky Avenue

Total Accessibility Jobs	Before	After
Total Accessibility in 0.5-mile buffer (Walking)	505	505
Total Accessibility in 2-mile buffer (Bicycling)	5,618	5,442
Total Accessibility in Transit buffer	1,696	1,717

Job Creation

A method similar to that used for calculating job creation for the San Fernando case study was used for the Kentucky Avenue complete street case study. The SACOG's proposed budget for the Kentucky Avenue complete street project is $12.573 million, expected to be completed by 2022 (SACOG, 2010; SACOG, 2013). Based on the calculations shown below, the total jobs created are:

- $12.573 * 7.61 * 50% = 48 Direct jobs
- $12.573 * 7.61 * 25% = 24 Indirect jobs
- $12.573 * 7.61 * 25% = 24 Induced jobs

From the budget of $12.573 million, a total of 96 jobs were estimated to be created for the construction of the Kentucky Avenue complete street project.

Connectivity Index

Different routes and options in a one-mile rectangular buffer (Figure 28) around Kentucky Avenue between East Street and West Street were calculated. One mile is considered as it is the length of Kentucky Avenue complete street project. As shown in Figure 28, three circles with a 1-mile diameter were drawn in the center and edges of Kentucky Avenue complete street, which made two by one square miles rectangle. The area of this rectangle was then measured to calculate the connectivity index via Google Earth and Google Maps.

Figure 28. Area Considered for measuring the Connectivity Index, Kentucky Avenue Case Study

Table 65 shows the selected indices description considered in the current study and connectivity results for Kentucky Avenue.

Table 65. Connectivity Results for Kentucky Avenue Case Study Based on the Selected Connectivity Indices

Measure	**Definition and Calculation**	**Notes**	**Before the construction of complete street (2016)**	**After the construction of complete street (2021)**
Intersection Density	Number of intersections in a given land area, such as a square mile or acre.	Can be limited to “3 and 4-leg intersections" or "intersections with pedestrian and bicycle accommodations", Typical Range For "Good" Connectivity: 100-160	106/ (2*1)= **53**	132/ (2*1)= **66**
Intersections per Linear Mile	Number of intersections in a given land area is divided by the linear network miles in the same area.	Can be limited to “3 and 4-leg intersections" or "intersections with pedestrian and bicycle accommodations.”	106/2/ (2*1)= **26**	132/2 (2*1)= **33**

Active Transportation to Local and Regional Transit Connectivity Index

Aerial imagery, Google Earth, and a static map were used to calculate this measure by selecting all the bikeway/walking path segments within a 1-mile buffer of regionally significant transit stations. The total bikeway miles within the buffer were then divided by land area within the buffer. The 2.0*1.0 square mile rectangle buffer around the County Fair Mall transit center, located at the intersection of East Gibson Road and East Street, is the only transit center in Woodland. However, because this center is more than 2-miles away from the Kentucky Avenue complete street, the bus stop located at the intersection of West Kentucky Avenue and North Cottonwood Street is considered as part of the network area (see Figure 29 and Figure 30). Table 66 shows the results for the active transportation transit connectivity index for Kentucky Avenue complete street.

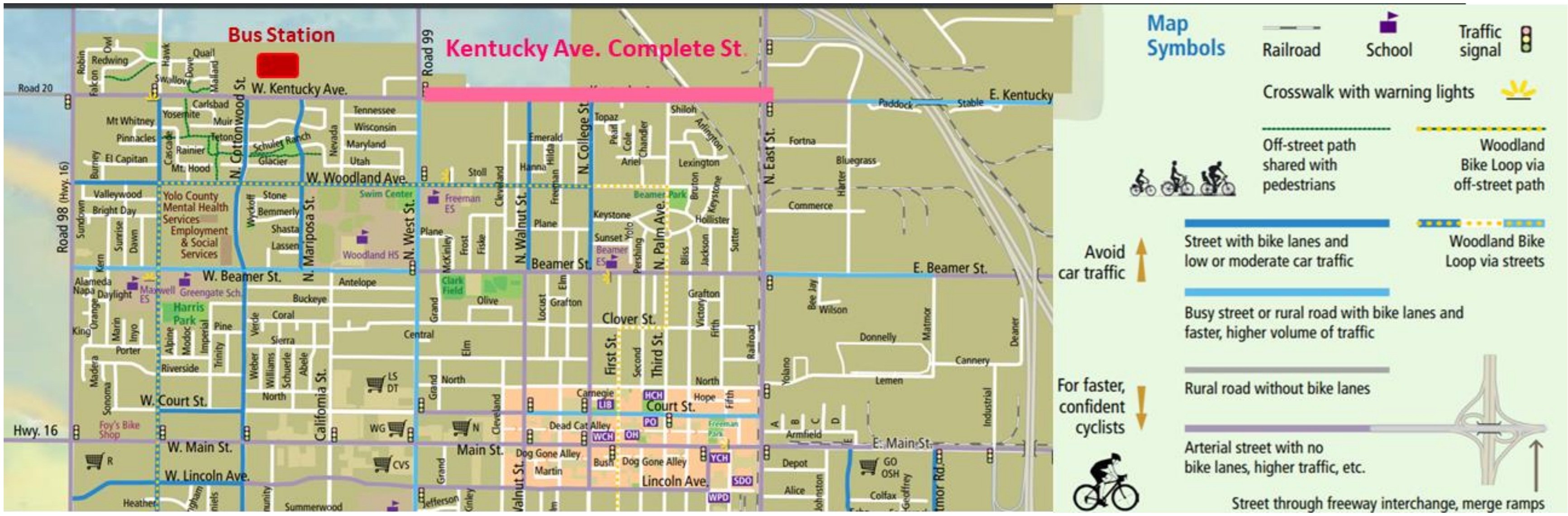


Figure 29. Woodland bike map based on Yolo County Bike Master Plan (Yolo County, 2013; Woodland Bike Map, 2017)

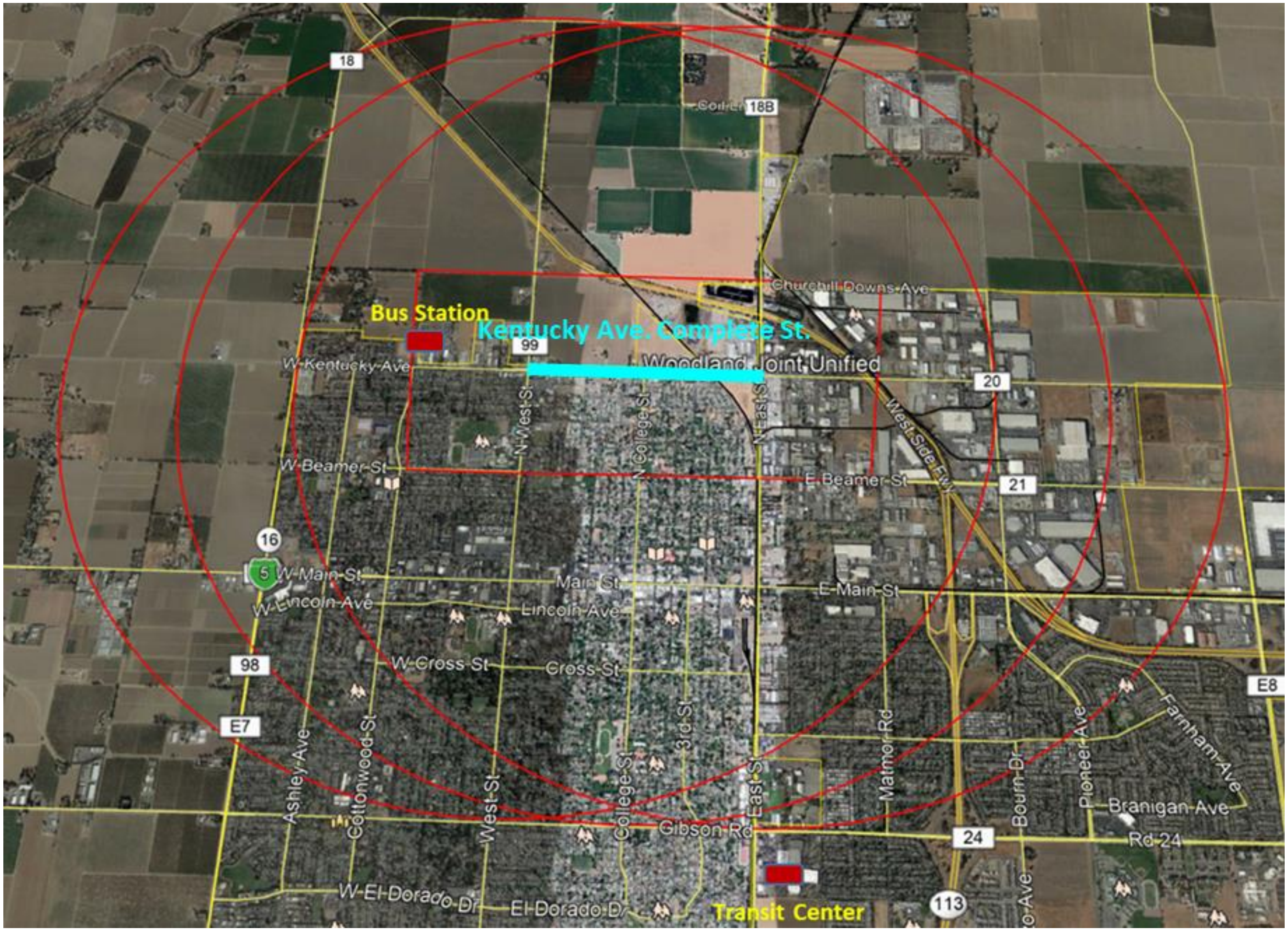


Figure 30. Kentucky Avenue Complete Street's buffer of regionally significant transit stations

Table 66. Results for the Active Transportation Transit Connectivity Index for Kentucky Avenue Complete Street Project

Measurement	**Before the construction of complete street (2017)**	**After the construction of complete street (2019)**
Mileage of bike/ ped. Lane (2-side)	**10.2** mile	**13.6** mile
Bike/ ped facility density (2-side)	10.2/(2*1)= **5.1**	13.6/(2*1)= **6.8**

Pedestrian and Bicyclist Delay

Dunn and Pretty's equations (Dunn and Pretty, 1984; FHWA, 1998) mentioned in the section of Performance Measures Considered in Complete Street Case Studies were used to calculate the pedestrian delays at signalized pedestrian crossings for the Kentucky Avenue case study. Table 67 and Table 68 were used to calculate the green interval duration.

This indicator was calculated for 2018 before the complete street was built and 2021 (after the complete street was built using Google Earth™ and Google Earth historical imagery features. Using these tools, there was a small difference (11% increase) in the amount of minor arterial delay and a considerable increase in the amount of major arterial delay (70% increase) between 2018 (before the complete street was built) and 2021 (after the complete street was built). Calculations for the total delays in a rectangular buffer (1-mile*2-mile) around the Kentucky Avenue before and after the construction of Kentucky Avenue complete street are presented in Table 67 and Table 68, respectively. Increases in pedestrian and bicycle delay are caused by changes in stop light timing and durations with changes in vehicle speed limits.

Table 67. Total delays in a rectangular buffer (1-mile*2-mile) around the Kentucky Avenue case study- Before the Complete Street Construction

g: vehicular green signal Formula	**d: Average delay (s) for narrow roadway (Minor arterial)** $d = \frac{(g+15)^2}{2\,(g+20)}$	**d: Average delay (s) for narrow roadway (Major arterial)** $d = \frac{(g+10)^2}{2\,(g+15)}$	**No. of arterial within 1-mile*2-mile buffer (Minor Arterial)**	**No. of arterial within 1-mile*2-mile buffer (Major Arterial)**	**Total delay(s) for Minor arterial**	**Total delay(s) for Major arterial**	**Total delay(s) in 1.6mile* 3.2mile buffer**
minimum green interval duration:	d= [(7+15)^2]/ [2*(7+20)]= **9 s**	d= [(11+10)^2]/ [2*(11+15)]= **8.5**	13	14	117	119	**236**
Minor arterial: 4-10 s (avg 7 s)							
Major arterial: 7-15 s (avg 11 s)							
maximum green interval duration:	d= [(40+15)^2]/ [2*(40+20)]= 25.2~ **25 s**	d= [(50+10)^2]/ [2*(50+15)]= 27.7 ~ **28**	13	14	325	392	**717**
Minor arterial: 40-50 s (avg 40 s)							
Major arterial: 40-60 s (avg 50 s)							
Average Delay					221	255	**476 sec (8 min)**

Table 68. Total delays in a rectangular buffer (1-mile*2-mile) around the Kentucky Avenue case study- After the Complete Street Construction

g: vehicular green signal Formula	**d: Average delay (s) for narrow roadway (Minor arterial)** $d = \frac{(g+15)^2}{2\,(g+20)}$	**d: Average delay (s) for narrow roadway (Major arterial)** $d = \frac{(g+10)^2}{2\,(g+15)}$	**No. of arterial within 1-mile* 2-mile buffer (Minor Arterial)**	**No. of arterial within 1-mile* 2-mile buffer (Major Arterial)**	**Total delay(s) for Minor arterial**	**Total delay(s) for Major arterial**	**Total delay(s) in 1.6mile* 3.2mile buffer**
minimum green interval duration: Minor arterial: 4-10 s (avg 7 s) Major arterial: 7-15 s (avg 11 s)	d= [(7+15)^2]/ [2*(7+20)]= **9 s**	d= [(11+10)^2]/ [2*(11+15)]= **8.5**	15	25	135	212	**347**
maximum green interval duration: Minor arterial: 40-50 s (avg 40 s) Major arterial: 40-60 s (avg 50 s)	d= [(40+15)^2]/ [2*(40+20)]= 25.2~ **25 s**	d= [(50+10)^2]/ [2*(50+15)]= 27.7 ~ **28**	15	25	375	700	**1,075**
Average Delay					255	456	**711 (12min)**

Level of Service

PLOS and BLOS

A lack of comprehensive data was a problem in calculating PLOS and BLOS for the Kentucky Avenue case study. Table 69 to Table 72 show the PLOS and BLOS results for the Kentucky Avenue complete street using both the HCM and NCHRP methodologies.

Table 69. NCHRP Link PLOS for Kentucky Avenue Case Study

	Before complete street was built		**After complete street was built**	
Average Link PLOS Number	3.52		1.79	
Link PLOS by direction	EB : 3.28	WB: 4.13	EB : 1.77	WB : 1.82

**EB: East Bound, and WB: West Bound*

Due to a lack of traffic data after constructing the complete street project, it is not easy to see how the NCHRP Link PLOS changed. A letter grade cannot be assigned to the NCHRP Link PLOS value (Table 69) because the letter LOS grade applies only to the full facility score and not to the link score. Besides, without calculating intersection BLOS, for which there is a lack of data, NCHRP PLOS was not recommended.

Table 70. HCM Link PLOS for Kentucky Avenue Complete Street

	Before complete street was built		After complete street was built	
HCM Link PLOS	EB	WB	EB	WB
	C (2.86)	D (4.17)	B (1.93)	B (1.98)
	D (3.52)		B (1.95)	

**EB: East Bound, and WB: West Bound*

The change in PLOS that can be seen in Table 70 is because of a change in the speed before and after the complete street.

Table 71. HCM Link BLOS Before and After Construction of Kentucky Avenue Complete Street

	Before complete street was built		After complete street was built	
Link BLOS	EB	WB	EB	WB
	D (3.63)	D (3.55)	C (3.42)	C (3.42)
	D (3.51)		C (3.42)	

A minor improvement in HCM link BLOS can be observed due to the change in the segment length (Table 71).

Table 72. NCHRP Link BLOS Before and After the Construction of Kentucky Avenue Complete Street

	Before complete street was built		After complete street was built	
Link BLOS	EB	WB	EB	WB
	F (5.49)	F (5.46)	E (4.71)	E (4.69)
	F (5.47)		E (4.70)	

The BLOS of E seen in Table 72 seems too low. The NCHRP methodology is very sensitive to the number of access points (e.g., driveways, side streets, etc.), so the segments with higher access point density have much lower LOS scores.

Regarding data collection, the length of the road was measured using Google Maps™. Road widths from before the Kentucky Avenue complete street construction (such as bike lane width, sidewalk width, lane width, etc.) were measured using Google Earth™ historical imagery. Road widths after the construction of the Kentucky Avenue complete street were measured in the field using a tape measure.

Urban LOS

According to the FHWA Traffic Data Pocket Guide (FHWA, 2018), the hourly design volume should be around 8% of the average daily traffic (ADT). This amount (8% suggested by FHW 2018) is higher than the ADT divided by 24 hours (4.16%). For Kentucky Avenue, the ADT of 11,635 from East Street to College Street and 10,067 from College Street to West Street were multiplied by 8% and divided by 2 to obtain the directional volume (City of Woodland, 2015).

Before the construction of the Kentucky Avenue complete street, LOS A indicates that the traffic flow speed is much more than half of the base free-flow speed (Table 73). Since the base free-flow speed is always faster than the posted speed limit, traveling with such a free-flow speed does not result in serious delays and congestion problems. To determine the amount of delay experienced by vehicles at signalized intersections, in addition to an urban LOS analysis, the calculation of intersection LOS is needed. However, the intersection LOS could not be calculated due to a lack of signal timing data and detailed traffic movement data.

Since there are no traffic data after the complete street construction, urban LOS should be updated with available traffic counts value after constructing the Kentucky CS project. Table 73 presents the urban level of service before the construction of Kentucky Avenue complete street.

Table 73. Urban Streets Level of Service for Before the Construction of Kentucky Avenue Complete Street

Segment	Travel Speed (mph)	LOS	Segment Length (feet)	BFFS*
East Street to College Street	32.1	A	2,646	40.0
College Street to West Street	32.2	A	2,652	40.0
Weighted average Speed	**32.2**			**40**
Travel Speed/BFFS = LOS	**80%**	**A**		

**BFFS is Base Free Flow Speed; Urban LOS is scored based on how fast traffic moves compared to the BFFS.*

Transit LOS

Since there is no bus service along the Kentucky complete street, TLOS before and after constructing this complete street project is F.

Level of Traffic Stress (LTS)

LTS tables derived from Northeastern University were used for calculating LTS for Kentucky Avenue (Furth, 2017). As shown in the detailed assessment shown in Appendix D, LTS after the construction of the Kentucky Avenue complete street for bikes riding on the road is 3 for westbound travel (Cleveland Street to West Street) and 4 for eastbound travel (East Street to Cleveland Street). The overall LTS improves from 4 to 3 after completing the Kentucky Avenue complete street (see Table 74). An LTS score of 3 indicates moderately high traffic stress, which is not suitable for most vulnerable groups.

Table 74. Level of Traffic Stress (LTS) Scores Comparing Before and After Building the Kentucky Avenue Complete Street

LTS Method	Before complete street was built	After complete street was built
Northeastern University Method	4 (High)	3 (Moderately High)

Crashes

For the Kentucky Avenue complete street project the number of bicycle-involved and pedestrian-involved crashes over five years was considered. Fatal car crashes and road traffic accidents in the Woodland 2014-2019 database was used for this measurement (City of Woodland Data Website, 2021). The 1-mile buffer area around Kentucky Avenue complete street was considered for calculating this indicator.

Table 75 presents the crash performance measure before and after the transition of Kentucky Avenue to a complete street. There is very little bicycle travel on Kentucky Avenue and only a few annual crashes occur, therefore a strong statement cannot be made regarding the influence of the Kentucky Avenue complete street project on this indicator.

Table 75. Number of Crashes in the 1.3-mile buffer areas around San Fernando complete street

Years	Number of Crashes (Streets within 2*1 sq miles rectangle buffer around Kentucky Avenue CS)	Number of Crashes (City of Woodland)	Before the Kentucky Avenue complete street= Average (2015-2018) = **1**
2014	1	4	
2015	1	2	
2016	1	3	
2017	1	3	
2018	0	3	
2019	0	1	After the Kentucky Avenue complete street= **0**

Pedestrian Miles Traveled / Bicycle Miles Traveled

The Yolo County Bicycle Transportation Plan report (Yolo County, 2013) was used to find the BMT performance measure data. According to this report, bike mode share will increase by 1.96% between 2010 and 2035 (Yolo County, 2013). This report show 2,600 and 2,780 bicyclists per day in Yolo county in 2018 and 2022, respectively. BMT is calculated for average trip lengths of 0.5 miles and 2 miles for Yolo County. Since no data specifically focus on Kentucky Avenue, this performance measure is not worthwhile for this rural complete street project.

Street Trees

The number of trees before building the Kentucky Avenue complete street was counted using Google Earth™ historical satellite images. The number of trees after constructing the complete street was counted using Google Maps Street-view.

Table 76. Number of Street Trees along the Kentucky Avenue Complete Street

Year	**Number of street trees**
2013 (before building the complete street)	35
2019 (after building the complete street)	119

As shown in Table 76, the number of street trees has increased because of a complete streets goal to improve livability and safety.

Street trees increase the number and duration of visits from the neighborhood because shading from trees improves the quality of walking and bicycling and brings people to the neighborhood, which is important for the neighborhood's economy. All of these factors also show the importance of street trees for business owners. They also improve air quality.

Chapter 5: Incorporation of Socioeconomic Data into the SLCA Model

For this project, the initial complete streets LCA framework was expanded to include assessment of the exposure of neighborhoods and their vulnerability to environmental impacts in conjunction with the performance indicators. This was done using the CalEnviroScreen tool from the California Environmental Protection Agency. Other tools similar to CalEnvironScreen can be used with the framework, such as the Social Vulnerability Index (CDC SVI no date) mapping tool developed and hosted by the federal Centers for Disease Control and Prevention. The consideration of exposure and vulnerability is intended to support the two concepts of best practices recommended by Hernandez (2021), location and sustainability, by considering the effects of complete streets on those living in, working in, and frequenting the neighborhood the complete street is located in.

CalEnviroScreen Tool

Overview

Developed by the Office of Environmental Health Hazard Assessment (OEHHA) with the California Environmental Protection Agency (CalEPA), CalEnviroScreen is an index used to identify populations in California census tracts disproportionately burdened by, and vulnerable to, multiple sources of pollution, poverty, and racial concentrations of residency. The CalEnviroScreen model is based on two key components: a pollution burden consisting of an array of indicators that identify exposures to pollution and the environmental effects of such exposure; and population characteristics consisting of an array of socioeconomic factors and indicators to identify sensitive populations (e.g. health status, race, income, age, etc.). Percentiles are then used to assign scores for each indicator for each census tract in the state. Scores for each indicator are then combined to produce an overall CalEnviroScreen score for each census tract in the state. Over 70 data elements covering socioeconomic data, race, poverty, pollutants, and contaminants were used to create this index making it one of the most useful indicators of residential segregation and environmental problems – two important characteristics of Priority Population Areas now targeted for public investment in state climate change legislation.

CalEnviroScreen is a simple but effective data source to help quickly identify patterns of racial residency and poverty, and concentrations of those most at risk of exposure to adverse environmental conditions. What is important to note here is that the spatial concentration of so many important indicators that make up the CalEnviroScreen index develop over extended periods of time under the influence of political and social factors that establish economic priorities – both public and private. More important, because CalEnviroScreen uses a large array of indicators to identify long-term concentrations of poverty, race, and risk to pollution exposure, it provides compelling evidence of long-term systemic inequality.[6]

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[6] Similar index-based mapping utilities for public investment can also be used to obtain data on census tract level or zip code level socio-economic conditions. Examples include the California Tax Credit Allocation Commission's

CalEnviroScreen can be used to identify disadvantaged neighborhoods for the complete street case studies on the map. Figure 31, Figure 32, and Figure 33 present the San Fernando Street, Franklin Boulevard, and Kentucky Avenue case study maps, respectively. Census tracts with darker red colors have higher CalEnviroScreen scores indicating relatively high pollution burdens and population sensitivities. Census tracts with lighter green colors have lower scores.

The data for the San Fernando Street complete street project show that the project area affects neighborhoods spanning a wide range of socioeconomic conditions. Data for the Franklin Boulevard complete street show that the project is in a low socioeconomic neighborhood. For the Kentucky Avenue complete street project, low CalEnviroScreen scores on the project's south side reflect the challenging socioeconomic conditions of the area. High CalEnviroScreen scores on the project's north side reflect an area with better socioeconomic conditions primarily consisting of a low population industrial area.

Based on these maps, a summary of the neighborhoods (i.e. census tracts) identified by CalEnviroScreen to be at least partially within the 0.5 and 2.0 mile distances from each complete street case study, the census tract populations, and the census tract CalEnviroScreen percentile rankings are shown in Appendix F. The CalEnviroScreen percentile rankings for each neighborhood by census tract were weighted by the populations in each census tract within walking or bicycling distance to create a summary population weighted summary CalEnviroScreen percentile ranking for each of the three complete streets considered in this study. The population weighted CalEnviroScreen percentile ranking was then normalized by the sum of the populations within the walking or biking distance across all three case studies. The normalized summary population weighted percentile rankings were intended for use as a first-order ranking metric for the relative impact of the complete street in terms of number of people in disadvantaged neighborhoods who could use the complete street across the three case studies. The equations used to calculate the normalized population weighted CalEnviroScreen percentile rankings for potential walking and biking populations are:

> CalEnviroScreen percentile ranking of the neighborhoods where pedestrians might use the complete street = Sum(populations in neighborhoods identified in CalEnviroscreen within 0.5 miles of the complete street*CalEnviroScreen percentile rankings for neighborhoods)/(Sum of all populations in neighborhoods within 0.5 miles of complete streets projects across all 3 case studies)
>
> CalEnviroScreen percentile ranking of the neighborhoods where bicyclists might use the complete street = Sum(populations in neighborhoods identified in CalEnviroscreen within 2.0 miles of the complete street*CalEnviroScreen percentile rankings for neighborhoods)/(Sum of all populations in neighborhoods within 2.0 miles of complete streets projects across all 3 case studies)

Opportunity Map https://belonging.berkeley.edu/2022-tcac-opportunity-map, the National Agency for Toxic Substances and Disease Registry's Social Vulnerability Index The Social Vulnerability Index (SVI): Interactive Map | CDC, and the Public Health Alliance's Healthy Places Index California Healthy Places Index Map.

This metric can be extended to consider bicycle or walking trips combined with transit.

The results are summarized in Table 77 for each street. The scores indicate that the San Fernando and Franklin Boulevard complete streets projects could potentially provide a benefit to more disadvantaged people compared with the Kentucky Avenue project. The results also show that the number of people living in CalEnviroScreen neighborhoods within 0.5 miles is greatest for the San Fernando and Kentucky Avenue projects compared with the Franklin Boulevard project. It can also be seen that the San Fernando project has a very large population within 2.0 miles of it, and that the Franklin Boulevard project has a greater population living within 2.0 miles of the complete street than the Kentucky Avenue project.

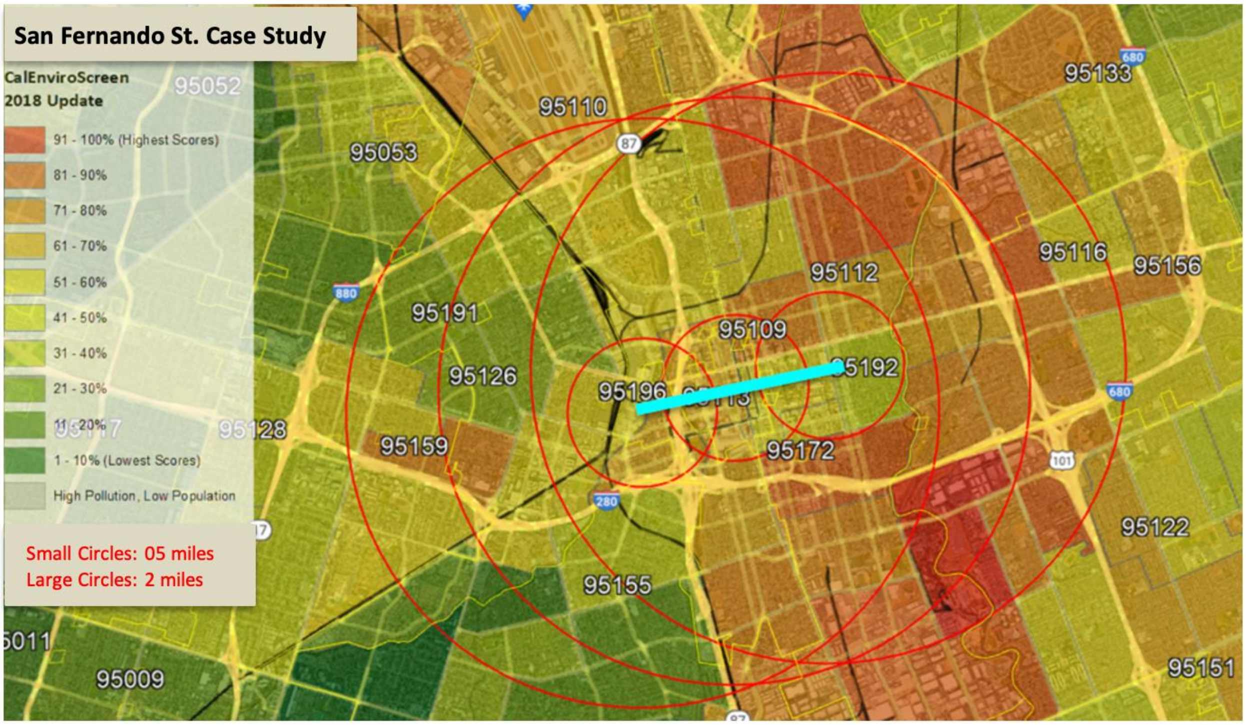

Figure 31. CalEnviroScreen Map showing the San Fernando Street Case Study. Notes: blue line indicates the complete street. Small red circles indicate 0.5 mile walking distance from complete street. Large red circles indicate 2.0 bicycling distance from complete street.

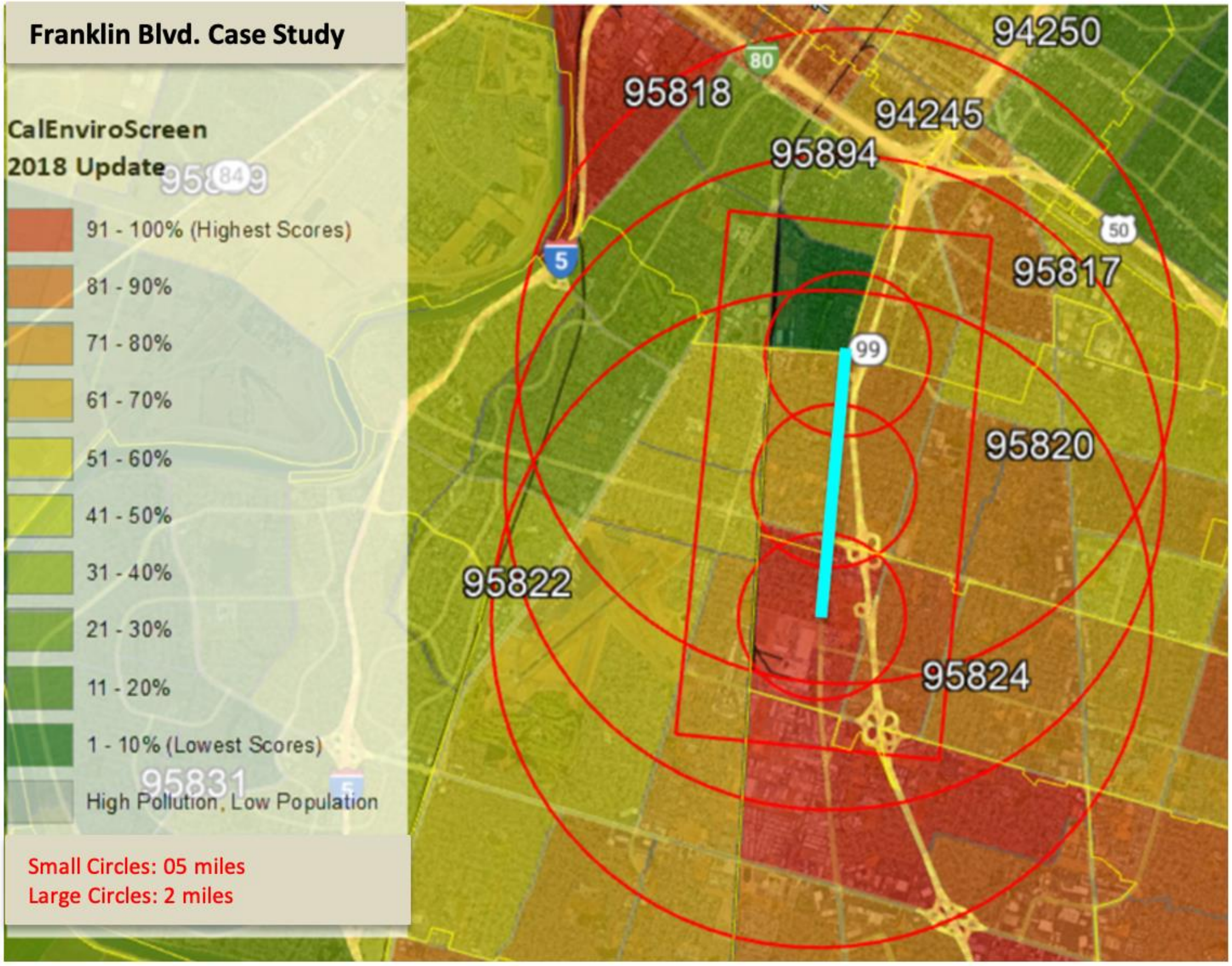

Figure 32. CalEnviroScreen Map showing the Franklin Boulevard Case Study. Notes: blue line indicates the complete street. Small red circles indicate 0.5 mile walking distance from complete street. Large red circles indicate 2.0 bicycling distance from complete street.

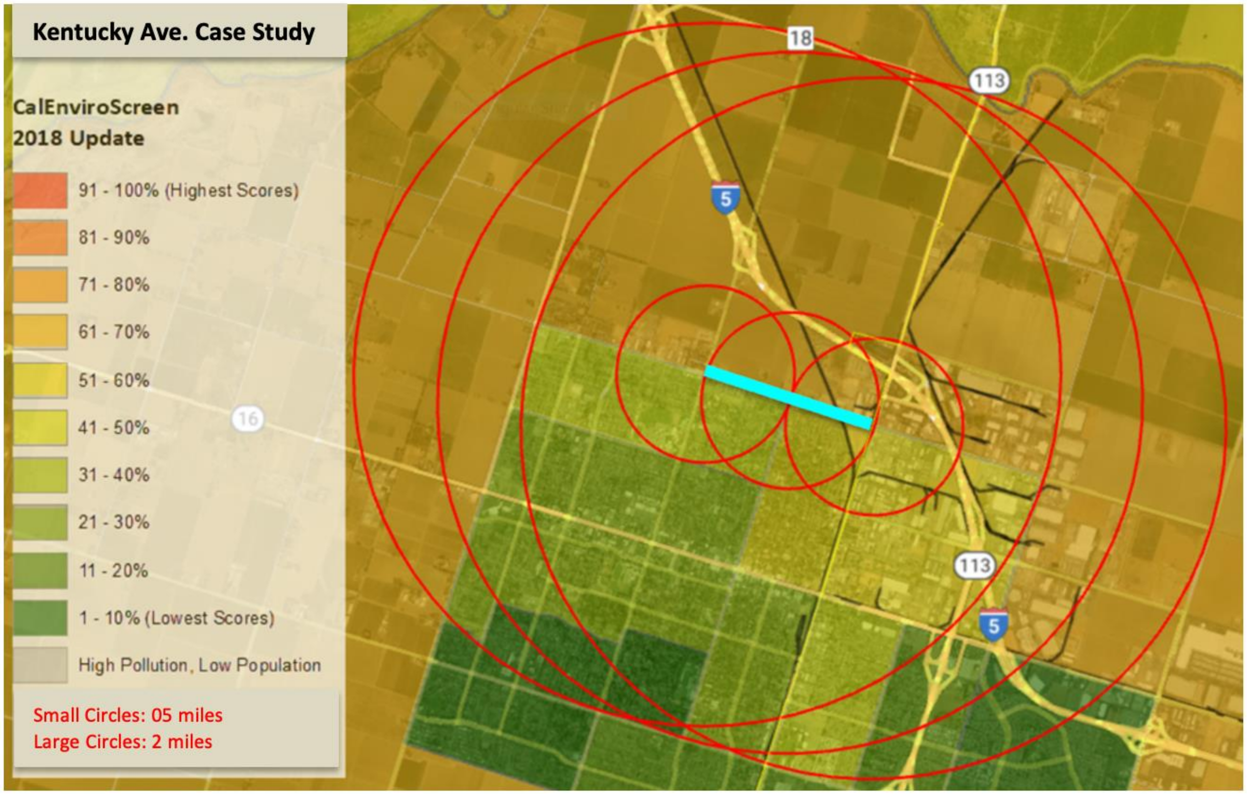

Figure 33. CalEnviroScreen Map showing the Kentucky Avenue Case Study. Notes: blue line indicates the complete street. Small red circles indicate 0.5 mile walking distance from complete street. Large red circles indicate 2.0 bicycling distance from complete street.

Table 77. Summary table of population weighted CalEnviroScreen percentile ranking for neighborhoods near complete streets.

Complete Street	Population within 0.5 miles	Population within 2.0 miles	Population weighted CalEnviroScore percentile rankings within 0.5 miles*	Population weighted CalEnviroScore percentile rankings within 2 miles*
San Fernando Street	18,418	163,708	63 (61-66)	64 (62-67)
Franklin Boulevard	11,261	79,988	61 (58-63)	63 (61-66)
Kentucky Avenue	16,521	20,767	55 (52-56)	47 (45-50)

*Note: Middle of range shown, numbers in parentheses are ranges from CalEnviroScreen

Chapter 6: Case Studies Summary SLCA Results

Summary results for the San Fernando Street, Franklin Boulevard, and Kentucky Avenue case studies are shown in in Table 78, Table 79, and Table 80, respectively.

Accessibility

Accessibility is divided into Access to Community Destinations, Access to Schools, and Access to Jobs are reported separately in the complete streets LCA framework. Access to Schools was separated from other destinations in the development of the original complete streets LCA framework based on feedback from a Complete Streets America panel that also included advocates for safe routes to schools. The panel said that schools were different from other destinations because they involved a unique vulnerable population and more focused set of destinations. Access to Jobs was separated because the methods for calculating it are somewhat different from calculations for other community destinations, and the difficulties of estimating numbers of jobs compared with determining numbers of community destinations.

Access indicators need to be interpreted with care. There are three issues to be concerned with for access indicators, as identified in the report on the development of the complete streets LCA framework (Harvey, 2018). The following is a condensed version of the discussion of those three concerns in that report.

> First, if the performance measure is written to produce the best value for the indicator (the highest value for accessibility) then a project in a neighborhood with a high level of previous investment in community destinations and greater density of them will produce a high value when a complete street accesses them. Alternatively, if the performance measure is written in terms of the improvement (change) in the indicator rather than the highest final value, then a disadvantaged project that may have a smaller number of community destinations that were more dispersed and that become accessible with the installation of the complete street may have a larger change in value. For this reason, the interpretation of access variable in the case studies considers both final accessibility value and change in value.
>
> Second, many performance indicators for transportation projects calculate accessibility in terms of the number of connections or improvement of connections to community destinations that a project will produce. What is missing from these performance indicators is the consideration of the number of community destinations that are in the neighborhood. A neighborhood with a greater density of community destinations will likely have a better accessibility indicator value than one where there has been underinvestment in community destinations because of the different densities, which has little to do with the complete street. The density of community destinations must be considered with interpreting access indicators.
>
> The mapping of community destinations and supporting infrastructure of different types in the neighborhood, as was done for the case studies, is a first

> step. If the mapping shows a low density of community destinations, it may be an indicator of lack of public investment in community destinations and their maintenance. In these cases, investment in access is not the only issue, and there is a need for investment in creating and maintaining more destinations as well as including active transportation access. In other words, creation of destinations and active transportation options to reach them need to be bundled together.
>
> A third consideration when identifying accessibility and connectivity performance measures is connectivity between neighborhoods by active transportation and/or active transportation combined with transit between adjacent neighborhoods. This type of network connectivity facilitates people coming into the neighborhood to create more economic opportunity for its businesses and facilitates people in the neighborhood being able to access community destinations in adjacent neighborhoods. The existing patterns of inter-neighborhood connections in many urban areas are often the result of historical transportation and housing planning decisions that resulted in segregation and limited connectivity between neighborhoods defined by race, ethnicity and/or income level. These were routinely created and enforced by race/ethnic/religious exclusions that were written into housing development covenants, sometimes by mortgage lending practices, sometimes by violence or the threat of it, and sometimes by elimination of connections by not building easy-to-use transportation connections or by placement of difficult-to-cross transportation facilities. Identifying and eliminating these inter-neighborhood barriers as part of the planning of complete streets is an important consideration.

These concerns are the background for the interpretation of the access indicators for the three case studies.

Access to Community Destinations

Community destinations are defined as those physical sites that provide access to the resources essential for neighborhood health and safety, social cohesion, and economic productivity. Access to these locations can also be thought of as access to the social goods needed for opportunity and mobility in the urban environment. Community destinations counted within the radii of walking and biking distances used in this study are grocery stores, pharmacies, hospitals and clinics, banks, post offices, libraries, coffee shops, restaurants, gas stations, police stations, places of worship, and museums.

Access to community destinations by any mode is determined by the number of community destinations, and access by complete street is determined by the number of destinations accessible by complete street. Increases in the access to community destinations by complete street indicator occur when destinations are within the walking and biking radii of the complete street, and when the number of community destinations is high. The indicator value will show less increase if the complete street does not provide access to many destinations. As noted previously, a low density of community destinations can cause a low value for this indicator. If there are people living near by and a low density of destinations this suggests that an investment in community destinations is likely warranted. If there are few people living near the complete street then the low density of destinations is an indication that the complete street might not be as useful compared to a more densely populated area. The intra-neighborhood accessibility increases if the complete street is part of a planned set of streets that create an interconnecting network, as opposed to a complete street that is not a link in a current or planned network (which was identified for each case study in Chapter 3).

The results shown in Table 78, Table 79, and Table 80 indicate that all of the complete streets increased access to community destinations by a complete street because there was no complete street previously. The number of San Fernando Street community destinations decreased from before to after the complete street for 7 of the 12 types of destinations.

Because the Access to Community Destinations performance indicator is dependent on the number of community destinations in the neighborhood, projects with different densities of destinations should not be compared. Interpretation of results within and between projects requires consideration of destination densities. Destinations were counted from before and after the complete streets project. Some analysis of changes in destination densities from before and after complete street construction was done for this study. Destination densities can change because of the complete street if the complete street design contributes to loss of destinations. However, most changes in the number of destinations within walking or biking distance of the complete street are caused by factors that have nothing to do with the complete street. Interpretation of access indicators needs to consider these changes should be done in practice.

Access to Schools

Access to schools is important for safety, and to improve livability and public health for children. Safety is the primary concern for active transportation access, but public health effects from physical activity, and potentially shorter travel times to schools allowing for more sleep for children and teens can also be beneficial, including consideration of sleep time for children and young adults (Voulgaries et al., 2019). Access to schools by a complete street increased from zero to all the destinations within the respective radii for walking and bicycling. Complete streets built near more schools will increase the value of this indicator.

A better assessment of the effects of the complete streets regarding changes in travel modes to school and perceived safety was obtained from use of the survey instrument for school principals developed in this project. As noted, the reopening of schools during the Covid pandemic is the likely reason that the survey had a very low response rate.

Access to Jobs

Access to jobs is a measure of the access of locations of employment to pedestrian, bicycle, and transit infrastructure and services. Easier accessibility to jobs reduces the need for driving to work and can make businesses more attractive for local employees. Connectivity by active transportation and/or active transportation combined with transit between a neighborhood and adjacent neighborhoods is also an important consideration. This type of connectivity facilitates people coming into a neighborhood to create more economic opportunities for its businesses and facilitates access to jobs for people in disadvantaged neighborhoods.

Access to jobs by a complete street increased from zero to all the destinations within the respective radii for walking and bicycling. Like access to community destinations, this access indicator is dependent on the number of community destinations in the neighborhood, particularly those offering employment.

Jobs

Job Creation

The purpose of this indicator is to identify whether the complete streets project will create jobs. All construction work will generate temporary construction jobs. The most value comes from new permanent jobs from new places of employment being attracted to the location, and from helping to retain permanent jobs by making the location a more attractive place to work.

As noted in the methodology part of this chapter, job creation was not directly measured, but was instead estimated using the Garrett-Peltier model. That model is tied to spending on the construction, which is a very indirect estimate of job creation for a specific project. Complete streets can be expected to attract new places of employment and retain existing businesses, if designed to support those employers. Despite the estimated positive results from the model shown for all three case studies by the job creation indicator seen in the summary tables, the results should be used with caution because they are generated from a regression model. A better approach would be to identify new businesses and associated jobs created by them after construction of the complete streets. However, whether the complete street was the direct cause would be difficult to identify without interviewing decision-makes at the employment locations, and after enough time for those locations to become established.

Job retention by making existing businesses, often likely to be owned by local residents in disadvantaged neighborhoods, is as important or potentially more important than new job creation. Job retention has no metric at this time, and was not able to be considered in these case studies.

Mobility/Connectivity

Connectivity Indices

One of the important roles of complete streets is to improve the ability of people in neighborhoods to reach destinations quickly and safely by walking or biking, or active transportation combined with transit. This includes the need to not have gaps in the route where active transportation is not safe and direct. The purpose of this index is to identify the ability to travel to different locations in the neighborhood by walking or bicycling, including consideration of the richness of within- and between-neighborhood transit points in a neighborhood.

The density of routes between neighborhoods and complete streets should be considered when interpreting this indicator. The indicator should look at the improvement in connectivity as opposed to the final value for connectivity because a neighborhood that has a high density of destinations will always have a higher connectivity. The changes in intersection density per linear mile were similar for San Fernando Street and Franklin Boulevard, approximately 13 to 15%, while the change in connectivity for Kentucky Avenue was approximately 25%.

Higher connectivity was found in the Franklin Boulevard case study which is along a dense business district. San Fernando Street had the next highest connectivity, followed by Kentucky Avenue which is has very few destinations on one side of the street.

Connectivity to Transit

This performance measure is important as it demonstrates the connectivity between neighborhood streets and larger corridors that are important connection points in the city transportation grid. For example, in San Jose, San Fernando Street, one of the main downtown streets, connects downtown San Jose to Diridon Station, which is the central passenger rail depot for San Jose and a transit hub for Santa Clara County and the Silicon Valley. Historical transportation and housing planning decisions have often resulted in the current patterns of poor inter-neighborhood connections in many urban areas. Limited connectivity contributes to segregation between neighborhoods by race, ethnicity, and income level (Hernandez, 2021).

San Fernando Street and Franklin Boulevard had the highest connectivity to transit after completion (or planned completion) of the complete street, and Franklin Boulevard had the greatest percent increase in connectivity percent, approximately 160% compared with approximately 95% for San Fernando Street. Kentucky Avenue had the lowest final connectivity to transit and had a 33% increase in connectivity to transit. As can be seen in Figure 30, Kentucky Avenue has one bus station approximately 0.5 miles from one end of the complete street, and the transit center is on the other side of the city outside the farthest active transportation/transit travel zone.

Safety and Public Health

Delay

Delay is an indicator of time it takes to complete a walking or bicycling trip. The desirable direction for delay from construction of complete streets is a topic of debate. Intersections can increase safety if they are signalized and the signals are set up to be accessible to pedestrians and bicyclists and timed for their crossing. Improved safety leads to a more useable environment, which ultimately has the effect of improving economic productivity when this investment happens on a business corridor. Delay’s effect may be negative and discourage people from using the street or the biking/walking facilities if a lot of time is spent on waiting at intersections. Therefore, when the delay is considered as a performance measure, the context of the complete street and the type of intersections and their effect on safety should also be considered. Delay may be caused by a lack of destinations and lack of connectivity, especially in disadvantaged neighborhoods, resulting in longer travel times.

There is an increase in the number of intersections in San Fernando Street, Franklin Boulevard, and Kentucky Avenue after the construction of the complete street projects, which increases the delay indicator. The results tables show the highest delay time after completion of the complete street for Franklin Boulevard, followed by San Fernando Street, and then Kentucky Avenue. The greatest increase in delay was on Kentucky Avenue (49%), followed by San Fernando Street (27%), and Franklin Boulevard (11%).

Level of Service

Level of service is a quality of service indicator that measures the way users might perceive a service condition (e.g., safety, travel time, delay, comfort, speed). Safety includes consideration of risk of collisions with vehicles for bicycles and pedestrians, risk of collisions between bicycles and pedestrians (particularly dangerous for seniors, children and people in wheelchairs), risk from obstacles (particularly dangerous for bicycles and people in wheelchairs), and ability to cross vehicle routes considering traffic gaps and signal timings. Safety also includes consideration of crime, including violent crime and robbery particularly important for children, seniors, women traveling alone and people in wheelchairs, and theft, particularly important for bicycles left at transit stations. in part determine the level of security perceived by travelers.

Some other active transportation and transit factors that affect the perception of LOS including safety are lighting, sight distances on routes and in the vegetation on the sides of routes (hiding places), level of maintenance, litter, noise, and adjacent heavy traffic (summaries available in Saelens and Handy, 2008; Cunningham and Michael, 2004; Humpel et al., 2002; Owen et al., 2004).

As mentioned in previous chapters, the Bicycle Level of Service (BLOS) and Pedestrian Level of Service (PLOS) methodologies were not designed to analyze all types of bike lanes and could not accurately reflect the improvements in bike safety, especially for the Franklin Boulevard and Kentucky Avenue case studies. Therefore, Bicycle Level of Traffic Stress (LTS), which can be applied to all these scenarios, is the recommended approach for all complete street projects.

The BLOS and PLOS for San Fernando Street did not change with the complete street, while they generally improved for Franklin Boulevard with some anomalies between methodologies. For Kentucky Avenue the BLOS improved or stayed the same depending on the methodology, while the PLOS improved.

The Bicycle Level of Traffic Stress improved for the San Fernando Street and Kentucky Avenue complete streets and improved dramatically for the Franklin Boulevard complete street.

Crashes increased somewhat for the San Fernando Street case, but may just reflect typical variability in a small geographical area over a short period of crash data collection. There was insufficient data to assess the other two complete streets.

Bicycle and Pedestrian Miles Traveled

These parallel indicators are the measurements of miles traveled in a specific location for a particular period by walking and bicycle. Creating bike lanes and pedestrian lanes by complete street design can be an important factor to make active transportation more viable in disadvantaged neighborhoods which can result in large improvement in PMT and BMT performance measures, if density of destinations of opportunity, transit connections and safety issues are addressed.

Bicycle miles traveled (BMT) and Pedestrian Miles Traveled (PMT) increased dramatically for downtown San Jose, which includes the San Fernando Street case, and increases are expected from modeling for the yet to be built Franklin Boulevard complete street. There was insufficient data to evaluate Kentucky Avenue.

Critiques of BMT and PMT

There is a debate regarding how PMT and BMT should be interpreted for complete street projects. On the one hand, these performance measures recognize increasing pedestrian and bicyclist trips if the distances to destinations are reasonable. On the other hand, long distances that people must travel by walking and bicycling to reach destinations will also show increasing BMT and PMT, which could also be an indication that there are few destinations in the neighborhood or poor connectivity (few direct routes). For example, in disadvantaged neighborhoods high PMT and BMT can be an indication that community destinations are sparse and widely spaced and people do not have access to vehicles and forced to walk or bicycle long distances, which has a negative social effect.

There are two ways to increase PMT and BMT. The first is to encourage people to walk instead of drive (positive desired direction for sustainability) by making driving more difficult and/or making walking and bicycling easier such as with a complete street and greater connectivity. The second is to increase the number of community destinations near housing or the density of housing near community destinations. Both of these strategies can be used together. It is suggested that the measure be modified to consider “trips” or “trip segments”, and include consideration of transit connected to complete streets as a means of increasing PMT and BMT trip segments and overcoming longer distances between destinations and housing.

Several questions should be answered in this regard, including:

- How multi-modal trips should be handled in terms of a trip counter
- How walking trips to transit and walking from the transit station to the final destination should be considered and counted
- How those walking trips and walking-transit trips should be distinguished

Research to determine the most effective combinations of PMT, BMT and PMT-transit and BMT-transit trip segments results in the greatest reduction in VMT and increase in bicycle and pedestrian trips would be valuable. One suggestion is to keep BMT/PMT and add bicycle/pedestrian trip numbers, which helps the framework not rewarding bad land use planning that results in few and far between community destinations that are far from housing.

The SLCA framework for complete streets and the consideration of multiple social indicators provides the opportunity for developing and testing improved social indicators.

Discussion and Interpretation

The main goal of this study was to test the socio-economic and environmental LCA of the complete street framework that was developed in an earlier study by the authors (Harvey et al., 2018). To achieve this goal, the team performed three case studies by and quantify the socio-economic and environmental impacts of complete streets and compare them with the conventional streets. Applying the framework to different case studies helps evaluate the proposed performance measures' usefulness, relevancy, and feasibility and make a possible modification.

Three case studies were considered in different parts of California to test the complete street framework, including the San Fernando Street complete street project located in San Jose, Franklin Boulevard complete street project located in Sacramento, and Kentucky Avenue complete street project located in Woodland, California. These case studies are located in more and less advantaged neighborhoods. The case studies include projects in urban areas and rural areas to compare the rural project with the urban projects.

The framework is based on five categories of concerns and 17 performance measures or indicators. Physical activity and green land consumption indicators were not considered in the current study because the data for these performance measures were unavailable. The main challenges in this study for the SLCA were data collection and interpretation difficulty for some of the indicators. Determining appropriate data sources took some time but was then easier once the data sources had been identified. Data for the pre-construction values was more difficult for those projects already built, San Fernando Street and Kentucky Avenue. It is intended that the framework will primarily be used prior to construction for evaluation of proposed projects for design and location, which will eliminate the need for finding the historical data that was needed for this research project. Predicting post-construction conditions for a complete street that has not yet been built, such as the Franklin Boulevard case study, is also inherently difficult. This is considered in the recommendations presented in the last chapter of this report for keeping or removing indicators from the framework. Every complete street project is unique, and this study discusses potential pitfalls in interpretation of some of the indicators, particularly when comparing one complete street project to another. Recommendations for avoiding those pitfalls when interpreting indicators in included in the discussion of the results from the case studies. Some of the models were appropriate for large areas and were not helpful to quantify or even quantifiable for the project-level complete street projects, such as green land consumption, and these indicators are recommended for removal from the framework in the final chapter.

The complete street LCA framework was purposefully for the interpretation of each individual indicator for support of decision-making for location, design and potentially for prioritization of complete streets. Each indicator was selected to address a specific potential benefit of the complete street project within its unique context. The intention is that decision-makers then use the individual indicator results and consider them in the context of the goals of each complete street project to support their decisions. The authors' view is that aggregating and weighting of the indicator scores to produce a single final SLCA score is inappropriate because each of the potential benefits should be considered against stated goals for the project, and because weighting of indicator results to produce a single value would need to be developed for each project based on the weighting of the unique goals for each project. Changes in the location and design of the project will change each indicator value differently. Also, communication between planners, designers and with stakeholders requires discussion of specific performance outcomes addressed by each indicator. Therefore, the desired direction for sustainability, and observed trend, and desired trend for each category and each indicator is provided in this report, instead of calculating only one final score.

The results summary of all the performance measures quantified for the three case studies are presented in Table 78, Table 79, and Table 80.

Table 78. Summary Results SLCA for San Fernando Street Case Study

Selected Category	Selected Performance Measures (Indicator)	Desired direction for sustainability	Accessible by conv. street before the construction of the CS	Accessible by CS before construction of CS	Accessible by complete street after construction of CS	Accessible by complete street difference between before and after building the CS	Unit per capita	Relative (normal-ized) difference (%)	Desired trend (Increase / Decrease /Direction)[1]	Observed trend (Increase / Decrease /Direction)[1]
Accessibility	Access to Community Destinations (0.5-mi)	Positive	94,170	0	70,076	70,076	Number of People having accessibility to Destination		**Inc**	**Inc**
	Access to Community Destinations (2-mi)	Positive	192,931	0	175,834	175,834				
	Access to Community Destinations (3-mi)	Positive	321,630	0	319,246	319,246				
	Access to Community Destinations (4.5-mi)	Positive	488,180	0	468,867	468,867				
	Access to school (0.5-mi)	Positive	402	0	402	402	Number of Students		**Inc**	**Inc**
	Access to school (2-mi)	Positive	2,895	0	2,895	2,895				
Jobs	Access to Jobs (0.5-mi)	Positive	21,053	0	19,546	19,546	Number of Employees having accessibility to Jobs		**Inc**	**Inc**
	Access to Jobs (2-mi)	Positive	27,209	0	26,692	26,692				
	Access to Jobs (3-mi)	Positive	50,022	0	52,485	52,485				
	Access to Jobs (4.5-mi)	Positive	76,530	0	78,241	78,241				
	Job Creation (Direct Jobs)	Positive	0		38		Number of Job Created		**Inc**	**Inc**
	Job Creation (Indirect Jobs)	Positive	0		19					
	Job Creation (Induced Jobs)	Positive	0		19					
	Job Creation (Total)	Positive	0		76					

Selected Category	Selected Performance Measures (Indicator)	Desired direction for sustainability	Accessible by conv. street before the construction of the CS	Accessible by CS before construction of CS	Accessible by complete street after construction of CS	Accessible by complete street difference between before and after building the CS	Unit per capita	Relative (normal-ized) difference (%)	Desired trend (Increase / Decrease /Direction)[1]	Observed trend (Increase / Decrease /Direction)[1]
Mobility / Connectivity	Connectivity Index (Intersection Density)	Positive	83		95	12	mile^{-2}	14.5%	**Inc**	**Inc**
	Connectivity Index (intersection per Linear Mile)	Positive	64		73	9	mile^{-3}	14.1%		
	Active Transportation to Local and Regional Transit Connectivity Index (Mileage of Bike/ Ped. Lane)	Positive	19.4		38	18.6	Mile	95.9%	**Inc**	**Inc**
	Active Transportation to Local and Regional Transit Connectivity Index (Bike/Ped. Facility Density)	Positive	5.8		11.2	5.4	mile^{-1}	93.1%		
	Pedestrian and Bicyclist Delay	Positive and Negative	677 sec (11 min)		871 sec (14 min)	194 sec (3 min)	Second /minutes	27.3%	**Dec/Inc**	**Inc**
	Level of Service (Urban or Auto)	Negative	C		C				**Dec**	**None**
Safety / Public Health	Level of Service (Bicycle Level of Service)-NCHRP	Positive	D		D				**Dec (Towards A)**	**None**
	Level of Service (Bicycle Level of Service)-HCM	Positive	C		C				**Dec (Towards A)**	**None**
	Level of Service (Pedestrian level of Service)- NCHRP	Positive	4.14		4.14				**Dec**	**None**

Selected Category	Selected Performance Measures (Indicator)	Desired direction for sustainability	Accessible by conv. street before the construction of the CS	Accessible by CS before construction of CS	Accessible by complete street after construction of CS	Accessible by complete street difference between before and after building the CS	Unit per capita	Relative (normal-ized) difference (%)	Desired trend (Increase / Decrease /Direction)[1]	Observed trend (Increase / Decrease /Direction)[1]
	Level of Service (Pedestrian level of Service)- HCM	Positive	B		B				**Dec (Towards A)**	**None**
	Level of Service (Transit level of Service)	Positive			F				**Dec (Towards A)**	**None**
	Bicycle Level of Traffic Stress (LTS)	Negative	2.5 (Moderately Low)		1 (Very Low)	1.5			**Dec**	**Dec**
	Crashes	Negative	79		92	13	Number of Crashes	16.5%	**Dec**	**Inc**
	Pedestrian Miles Traveled (0.5-mile) [2]	Positive and Negative	7,799		31,135	23,336	Ped* miles/day	299%	**Inc**	**Inc**
	Pedestrian Miles Traveled (2-mile)[2]	Positive and Negative	31,194		124,540	93,346	Ped* miles/day	299%	**Inc**	**Inc**
	Bicycle Miles Traveled (0.5-mile) [2]	Positive and Negative	2,279		6,101	3,822	Bike* miles/day	168%	**Inc**	**Inc**
	Bicycle Miles Traveled (2-mile) [2]	Positive and Negative	8,916		24,404	15,488	Bike* miles/day	174%	**Inc**	**Inc**
Livability	Street Trees	Positive	136		127	-9	Number of trees	-6.6%	**Inc**	**Dec**

[1] Inc = increased, Dec = decreased, None = No change

[2] For entire downtown San Jose, not just San Fernando Street

Table 79. Summary Results SLCA for Franklin Boulevard Case Study

Selected Category	Selected Performance Measures (Indicator)	Desired direction for Sustain-ability	Accessible by conv. street before the construction of the CS	Accessible by CS before construction of CS	Accessible by complete street after construction of CS	Accessible by complete street difference between before and after building the CS	Unit per capita	Relative (normal-ized) difference (%)	Desired trend (Increase/ Decrease/ Direction)[1]	Observed trend (Increase/ Decrease/Direction)[1]
Accessibility	Access to Community Destinations (0.5-mi)	Positive	24,468	0	27,159	27,159	Number of People having accessibility to Destinations		**Inc**	**Inc**
	Access to Community Destinations (2-mi)	Positive	138,534	0	153,773	153,773				
	Access to Community Destinations (Polygon Transit Buffer)	Positive	44,772	0	49,697	49,697				
	Access to school (0.5-mi)	Positive	762	0	762	762	Number of Students		**Inc**	**Inc**
	Access to school (2-mi)	Positive	7,666	0	7,666	7,666				
Jobs	Access to Jobs (0.5-mi)	Positive	1,857	0	3,008	3,008	Number of Employees having accessibility to Jobs		**Inc**	**Inc**
	Access to Jobs (2-mi)	Positive	13,469	0	21,820	21,820				
	Access to Jobs (Polygon Transit Buffer)	Positive	3,671	0	5,947	5,947				
	Job Creation (Direct Jobs)	Positive	0		35	35	Number of Created Jobs		**Inc**	**Inc**
	Job Creation (Indirect Jobs)	Positive	0		18	18				
	Job Creation (Induced Jobs)	Positive	0		17	17				
	Job Creation (Total)	Positive	0		70	70				

Selected Category	Selected Performance Measures (Indicator)	Desired direction for Sustain-ability	Accessible by conv. street before the construction of the CS	Accessible by CS before construction of CS	Accessible by complete street after construction of CS	Accessible by complete street difference between before and after building the CS	Unit per capita	Relative (normal-ized) difference (%)	Desired trend (Increase/ Decrease/ Direction)[1]	Observed trend (Increase/ Decrease/Direction)[1]
Mobility / Connectivity	Connectivity Index (Intersection Density)	Positive	145		164	19	mile^{-2}	13%	**Inc**	**Inc**
	Connectivity Index (intersection per Linear Mile)	Positive	45		51	6	mile^{-3}	13%		
	Active Transportation to Local and Regional Transit Connectivity Index (Mileage of Bike/ Ped. Lane)	Positive	15.6		40.2	24.6	Mile	157.7%	**Inc**	**Inc**
	Active Transportation to Local and Regional Transit Connectivity Index (Bike/Ped. Facility Density)	Positive	3		7.8	4.8	mile^{-1}	160.0%		
	Pedestrian and Bicyclist Delay	Positive and Negative	3645 sec (61 min)		4062 sec (68 min)	417 sec (7 min)	Second /minutes	11.5%	**Inc/Dec**	**Inc**
	Level of Service (Urban or Auto)	Negative	B		C				**Dec**	**Inc**
Safety / Public Health	Level of Service (Bicycle Level of Service)-NCHRP	Positive	D		D				**Dec (Towards A)**	**None**
	Level of Service (Bicycle Level of Service)-HCM	Positive	D		A				**Dec (Towards A)**	**Dec**
	Level of Service (Pedestrian level of Service)- NCHRP	Positive	2.54		0.15				**Dec**	**Dec**

Selected Category	Selected Performance Measures (Indicator)	Desired direction for Sustain-ability	Accessible by conv. street before the construction of the CS	Accessible by CS before construction of CS	Accessible by complete street after construction of CS	Accessible by complete street difference between before and after building the CS	Unit per capita	Relative (normal-ized) difference (%)	Desired trend (Increase/ Decrease/ Direction)[1]	Observed trend (Increase/ Decrease/Direction)[1]
	Level of Service (Pedestrian level of Service)- HCM	Positive	D		B				**Dec (Towards A)**	**Dec**
	Level of Service (Transit level of Service)	Positive	F		F				**Dec (Towards A)**	**None**
	Bicycle Level of Traffic Stress (LTS)	Negative	4 (High)		1 (Very low)	3			**Dec**	**Dec**
	Crashes (bike/ped)	Negative	18				Number of Crashes		**Dec**	**No data**
	Pedestrian Miles Traveled (0.5-mile)	Positive and Negative	1,433		1,211	28	Ped* miles/day	545%	**Inc/Dec**	**Inc**
	Pedestrian Miles Traveled (2-mile)	Positive and Negative	5,732		4,844	110	Ped* miles/day	545%	**Inc/Dec**	**Inc**
	Bicycle Miles Traveled (0.5-mile)	Positive and Negative	261		176	2	bicycle* miles/day	207%	**Inc/Dec**	**Inc**
	Bicycle Miles Traveled (2-mile)	Positive and Negative	1,044		704	6	bicycle* miles/day	207%	**Inc/Dec**	**Inc**
Livability	Street Trees	Positive	49		349	300	Number of trees	612%	**Inc**	**Inc**

[1] Inc = increased, Dec = decreased, None = No change

Table 80. Summary Results SLCA for Kentucky Avenue Case Study

Selected Category	Selected Performance Measures (Indicator)	Desired direction for Sustainability	Accessible by conv. street before the construction of the CS	Accessible by CS before construction of CS	Accessible by complete street after construction of CS	Accessible by complete street difference between before and after building the CS	Unit per capita	Relative (normal-ized) difference (%)	Desired trend (Increase/ Decrease/ Direction)[1]	Observed trend (Increase / Decrease / Direction)[1]
Accessibility	Access to Community Destinations (0.5-mi)	Positive	7,926	0	7,926	7,926	Number of People having accessibility to Destinations		**Inc**	**Inc**
	Access to Community Destinations (2-mi)	Positive	74,945	0	71,258	71,258				
	Access to Community Destinations (Polygon Transit Buffer)	Positive	20,268	0	20,426	20,426				
	Access to school (0.5-mi)	Positive	1,285	0	1,285	1,285	Number of Students		**Inc**	**Inc**
	Access to school (2-mi)	Positive	5,361	0	5,361	5,361				
Jobs	Access to Jobs (0.5-mi)	Positive	505	0	505	505	Number of Employees having accessibility to Jobs		**Inc**	**Inc**
	Access to Jobs (2-mi)	Positive	5,618	0	5,442	5,442				
	Access to Jobs (Polygon Transit Buffer)	Positive	1,696	0	1,717	1,717				
	Job Creation (Direct Jobs)	Positive	0		48	48	Number of Created Jobs		**Inc**	**Inc**
	Job Creation (Indirect Jobs)	Positive	0		24	24				
	Job Creation (Induced Jobs)	Positive	0		24	24				
	Job Creation (Total)	Positive	0		96	96				

Selected Category	Selected Performance Measures (Indicator)	Desired direction for Sustainability	Accessible by conv. street before the construction of the CS	Accessible by CS before construction of CS	Accessible by complete street after construction of CS	Accessible by complete street difference between before and after building the CS	Unit per capita	Relative (normal-ized) difference (%)	Desired trend (Increase/ Decrease/ Direction)[1]	Observed trend (Increase / Decrease / Direction)[1]
Mobility / Connectivity	Connectivity Index (Intersection Density)	Positive	53		66	13	mile^{-2}	25%	**Inc**	**Inc**
	Connectivity Index (intersection per Linear Mile)	Positive	26		33	7	mile^{-3}	27%		
	Active Transportation to Local and Regional Transit Connectivity Index (Mileage of Bike/ Ped. Lane)	Positive	10.2		13.6	3.4	Mile	33.3%	**Inc**	**Inc**
	Active Transportation to Local and Regional Transit Connectivity Index (Bike/Ped. Facility Density)	Positive	5.1		6.8	1.7	mile^{-1}	33.3%		
	Pedestrian and Bicyclist Delay	Positive and Negative	476 sec (8 min)		711 sec (12 min)	235 sec (4 min)	Second /minutes	49.4%	**Inc/Dec**	**Inc**
	Level of Service (Urban or Auto)	Negative	A		No data					**No data**
Safety / Public Health	Level of Service (Bicycle Level of Service)-NCHRP	Positive	F		F				**Dec (Towards A)**	**None**
	Level of Service (Bicycle Level of Service)-HCM	Positive	D		C				**Dec (Towards A)**	**Dec**
	Level of Service (Pedestrian level of Service)- NCHRP	Positive	3.52		1.79				**Dec**	**Dec**

Selected Category	Selected Performance Measures (Indicator)	Desired direction for Sustainability	Accessible by conv. street before the construction of the CS	Accessible by CS before construction of CS	Accessible by complete street after construction of CS	Accessible by complete street difference between before and after building the CS	Unit per capita	Relative (normal-ized) difference (%)	Desired trend (Increase/ Decrease/ Direction)[1]	Observed trend (Increase / Decrease / Direction)[1]
	Level of Service (Pedestrian level of Service)- HCM	Positive	D		A				**Dec (Towards A)**	**Dec**
	Level of Service (Transit level of Service)	Positive	F		F				**Dec (Towards A)**	**None**
	Bicycle Level of Traffic Stress (LTS)	Negative	4 (High)		3 (Moder-ately High)	3			**Dec**	**Dec**
	Crashes (bike/ped)	Negative	1		0		Number of Crashes		**Dec**	**Dec**
	Pedestrian Miles Traveled (0.5-mile)	Positive and Negative	NO DATA		NO DATA		Ped* miles/day		**Inc/Dec**	**None**
	Pedestrian Miles Traveled (2-mile)	Positive and Negative	NO DATA		NO DATA		Ped* miles/day		**Inc/Dec**	**None**
	Bicycle Miles Traveled (0.5-mile)	Positive and Negative	1,301		1,390	89	bicycle* miles/day	7%	**Inc/Dec**	**Inc**
	Bicycle Miles Traveled (2-mile)	Positive and Negative	5,205		5,560	355	bicycle* miles/day	7%	**Inc/Dec**	**Inc**
Livability	Street Trees	Positive	35		119	84	Number of trees	240.0%	**Inc**	**Inc**

[1] Inc = increased, Dec = decreased, None = No change

Chapter 7: Environmental Life Cycle Assessment

Introduction

This chapter evaluates the environmental part of the socio-economic and environmental LCA framework developed for complete streets by Harvey et al (2018). The framework is used to quantify the environmental impacts of complete streets and compare them with the existing vehicle-centric configuration streets. Complete streets that have not yet been constructed are evaluated using the city/county design documents for that project.

Some results of the complete street framework application are assessed in a sensitivity analysis on the three case studies before (conventional street) and after (complete street) the construction of the complete streets. Changes in vehicle miles traveled and speed are also considered before and after building the complete streets in all three case studies.

Environmental LCA Modeling and Assumptions

The scope of the LCA study in this chapter is limited to material production, transportation of raw materials from the extraction site to a processing plant and from there to the construction site, construction activities (cradle-to-laid), and vehicle use in the use stage. The use stage scope includes changes in vehicle miles traveled (VMT) and vehicle speed and their effects on selected emissions from the well to pump (production) and pump-to-wheel (combustion) perspective. The evaluation does not include the end-of-life of the built infrastructure, or any other effects on vehicles, or the use of alternative modes of transportation instead of motorized vehicles. Only passenger cars and light-duty trucks (SUVs) that burn gasoline are considered, and this study does not assume any heavier freight vehicles. The assumption of no heavy vehicles will underestimate the thickness of the pavement needed and the vehicle emissions. Truck count data were not available.

The analysis period was assumed to be 30 years. The reduction in VMT for each case study was used for offsetting the extra emissions due to the material and construction for complete street (CS-) options compared to conventional (Conv-) options in the sensitivity analysis. The functional unit is one block of the complete street for each of the three case studies.

The Sacramento County Office of Engineering Improvement Standard (Sacramento County 2009) was used to determine the pavement layer thicknesses. Pavement width and block length were determined using Google Maps™ and Google Earth™. Kentucky Avenue was visited by one of the authors to record the street features needed for the analysis. The summary of the layer type and road dimensions for all the cases is presented in Table 81.

Table 81. Street Dimensions for the three case study streets

Case Study	Aggregate Base Thickness [cm (in)]*	Asphalt Concrete Thickness [cm (in)]*	Complete Street Pavement Width [m (ft)]	Block Length [m (ft)]
San Fernando Street	33 (13)	9 (3.5)	13 (42)	81 (265)
Franklin Boulevard	33 (13)	9 (3.5)	13 (42)	104 (340)
W. Kentucky Avenue	25 (10)	9 (3.5)	10 (32)	270 (886)
E. Kentucky Avenue	33 (13)	9 (3.5)	13 (42)	270 (886)

*Assumed based on assumption of no heavy trucks

In the current study, the GaBi software, which is a commercial LCA software developed by thinkstep, Inc. (now owned by Sphera), was used to develop models for each case. The impact indicators are from TRACI 2.1, developed by the US Environmental Protection Agency (US EPA; Bare 2012), for the life cycle impact assessment (LCIA).

The authors have performed a detailed study to develop pavement construction material and energy models that are specific to California conditions and they can be found in the UCPRC LCI report (Saboori et al., 2021). These inventories were used to perform the eLCA for the three case studies. The materials and energy models used from Saboori et al (2021) for this study are in Appendix E in the archived data for this project. Some other items commonly used in complete streets, such as paint and plantings, were taken from the complete street LCA framework report (Harvey et al., 2018).

Three main impact categories are of particular importance and interest in California: global warming potential (GWP), photochemical ozone creation potential or also called smog formation, and the effects of particulate matter that are smaller that 2.5 microns on human health. These three TRACI impact indicators were considered in this study. Primary energy demand (PED) from non-renewable and renewable sources LCIs from GaBi were used to quantify the energy indicator for each case study. Feedstock energy or Primary Energy Demand (Non-Fuel) is the energy stored in the construction materials that are not consumed (such as asphalt; ISO 2006, Butt et al., 2019; Ostovar et al., 2020) and is also quantified for the three case studies. All the indicators considered in this report are summarized as:

- Global Warming Potential (GWP): in kg of CO2e.
- Photochemical Ozone Creation Potential: in POCP: in kg of O3e in TRACI (a measure of smog formation or SFP).
- Human Health (PM2.5): in kg of PM2.5 (particulate matters smaller than or equal to 2.5 micrometers in diameter).
- Total Primary Energy Demand: used as fuel from renewable and non-renewable resources (net calorific value excluding feedstock energy): in MJ.
- Feedstock Energy is Primary Energy Demand used as a material from nonrenewable resources (also called PED [non-fuel]): in MJ.

According to the LCA framework for complete streets, a typical list of all the complete street elements is shown in Table 82 (Harvey et al., 2018). Table 116 and Table 120 (in Appendix E in the data archive), extracted from the complete street LCA framework, show the LCI and LCIA of the materials and surface treatments needed to calculate the LCI and LCIA of the complete street elements (Table 82). The LCIA is summarized in Appendix E of this report.

Table 82. Complete Street Elements

Complete Street Element (a single Item)	Service Life (yrs)	Material Used
Buffered Cycle Track	3	Paint (area)
Coloring Lanes	3	Paint (area)
Curb Extension	15	PCC[1] on AB[2]
Curb Type 5	15	PCC
Island	15	PCC on AB
Planted Furniture Zone	5	Planting
Raised Bicycle Buffer	10	HMA[3] (overlay)
Raised Cycle Track	10	HMA (overlay)
Raised Middle Lane	10	HMA (overlay)
Raising the Intersection to Sidewalk Grade	10	HMA (overlay)
Shelter/Transit station	15	PCC on AB
Striping	3	Paint (linear)
Textured/Pervious Pavement	10	Permeable HMA
Widening Sidewalk	15	PCC on AB

[1] PCC = Portland cement concrete

[2] AB = Agrregate base

[3] HMA = Hot mix asphalt

Service life was assumed for each element of conventional and complete streets separately (shown later) to determine the number of times each element needs to be treated/replaced during the 30-year analysis period with a typical maintenance, rehabilitation, or reconstruction treatment. According to the framework, it was assumed that the entire conventional street and complete street infrastructure would be replaced at the end of their service life.

Results and Discussion

San Fernando Street Case Study

The input used to calculate the environmental impacts for the San Fernando Street are presented in Table 83. Table 84 and Table 86 show the needed information to calculate the itemized impacts during the 30 years analysis period for conventional options and complete street options, respectively. Table 85 and Table 87 represent the impact categories of the San Fernando Street case study during the material, transportation, and construction stages (absolute values) before and after building the complete street, respectively.

Table 83. Input needed for San Fernando Complete Street Case study

Case Study	Block Length (m)	Complete Street Width (m)	Daily Traffic (#Cars/ Day)	% Change in Emission Rates	Min. AB[2] Thickness (cm)	Min. HMA[3] Thickness (cm)	Vehicle Speed on the Street (km/h)
San Fernando Street	81	12.80	9957	0.0%	33	8.89	40

[1] VMT = Vehicle miles traveled

[2] AB = Aggregate base

[3] HMA = Hot mix asphalt

Table 84. Input required for the Conventional Options to Calculate the Itemized Impacts for Materials, Transportation, and Construction Stages- San Fernando Street

Treatment (during the analysis period)	Functional Unit	Service Life (yrs)	Thick-ness (cm)	# of Treatment Applications	Traveled Way Width (m)	# per block	Note
HMA[1] (overlay)	1 Block	10.0	8.9	3	3.70	3	Street Top Layer
Aggregate, Crushed	1 Block	15.0	33.0	2	3.70	3	Street AB[3]
PCC[2]	1 Block	20.0	15.2	2	0.91	2	Curb & Gutter Surface
Aggregate, Crushed	1 Block	15.0	15.2	2	0.91	2	Curb & Gutter AB
Planting	1 Block	5.0	NA	6	1.83	2	Landscape
PCC	1 Block	20.0	9.2	2	1.52	2	Sidewalk Surface
Aggregate, Crushed	1 Block	15.0	15.2	2	1.52	2	Sidewalk AB

[1] HMA = Hot mix asphalt

[2] PCC = Portland cement concrete

[3] AB = Aggregate base

Table 85. Absolute Values of Impact Categories for the Conventional Options for Materials, Transportation, and Construction Stages- San Fernando Street

Treatment (during the analysis period)	Note	Functional Unit	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]	Share of this item in Total GWP[4]
HMA[1] (overlay)	Street Top Layer	1 Block	3.33E+04	4.21E+03	2.13E+01	3.80E+05	1.21E+06	40.6%
Aggregate, Crushed	Street AB[3]	1 Block	1.77E+04	3.14E+03	6.75E+00	2.73E+05	0.00E+00	21.6%
PCC[2]	Curb & Gutter Surface	1 Block	1.38E+04	1.28E+03	7.57E+00	1.07E+05	0.00E+00	16.9%
Aggregate, Crushed	Curb & Gutter AB	1 Block	1.17E+03	2.07E+02	4.45E-01	1.80E+04	0.00E+00	1.4%
Planting	Landscape	1 Block	1.91E+01	1.07E+01	6.56E-02	7.71E+02	0.00E+00	0.0%
PCC	Sidewalk Surface	1 Block	1.39E+04	1.29E+03	7.63E+00	1.08E+05	0.00E+00	17.0%
Aggregate, Crushed	Sidewalk AB	1 Block	1.95E+03	3.45E+02	7.42E-01	3.00E+04	0.00E+00	2.4%
Total		**1 Block**	**8.19E+04**	**1.05E+04**	**4.45E+01**	**9.17E+05**	**1.21E+06**	

[1] HMA = Hot mix asphalt

[2] PCC = Portland cement concrete

Table 86. Inputs needed for the Complete Street Options to Calculate the Itemized Impacts for Materials, Transportation, and Construction Stages- San Fernando Street

CS Element	Material	Service Life (yrs)	# per Block	Length (m)	Width (m)	Area of the Element (m^2)	% of area that is replacing conventional treatment
Coloring Lanes	Paint (area)	3	2	81	2.44	197	0%
Shelter/Transit station	PCC[1] on AB[2]	15	1	15	3.00	45	100%
Planted Furniture Zone	Planting	5	1	61	3.00	182	100%
Curb Type 5	PCC	15	1		NA	NA	0%
Coloring Lanes	Paint (area)	3	2			0	0%
Raised Bicycle Buffer	HMA[3] (overlay)	10	2	81	NA	NA	0%
Buffered Cycle Track	HMA (overlay)	3	2	81	1.52	123	100%

[1] PCC = Portland cement concrete

[2] AB = Aggregate base

[3] HMA = Hot mix asphalt

Table 87 shows the breakdown of total GWP between the conventional elements and complete street elements. According to this table, 95% of the total GWP in the material, transportation, and construction stages belongs to the conventional elements, including the pavement, curbs, and gutters, etc., and only 5% of the total GWP belongs to the complete street elements.

Table 87. Absolute Values of Impact Categories for the Complete Street (After the CS Construction) for Materials, Transportation, and Construction Stages- San Fernando Street

CS Element	**Material**	**GWP [kg CO2e]**	**POCP [kg O3e]**	**PM2.5 [kg]**	**PED (Total) [MJ]**	**PED (Non-Fuel) [MJ]**	**Share of this item in Total GWP**
Complete Street Options							
Coloring Lanes	Paint (area)	6.77E-03	8.33E-02	6.19E-07	1.09E-02	0.00E+00	4.7%
Shelter/Transit station	PCC[1] on AB[2]	3.75E+03	3.77E+02	1.99E+00	3.17E+04	0.00E+00	
Planted Furniture Zone	Planting	1.18E+01	2.45E+00	1.50E-02	1.76E+02	0.00E+00	
Curb Type 5	PCC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Coloring Lanes	Paint (area)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Raised Bicycle Buffer	HMA[3] (overlay)	2.26E+02	2.86E+01	1.45E-01	2.59E+03	8.22E+03	
Buffered Cycle Track	HMA (overlay)	1.27E-03	1.56E-02	1.16E-07	2.05E-03	0.00E+00	
Total (Complete Street Impacts)		*3.99E+03*	*4.08E+02*	*2.15E+00*	*3.45E+04*	*8.22E+03*	
Conventional Options							
Treatment (during the analysis period)	**Note**	**GWP [kg CO2e]**	**POCP [kg O3e]**	**PM2.5 [kg]**	**PED (Total) [MJ]**	**PED (Non-Fuel) [MJ]**	95.3%
HMA (overlay)	Street Top Layer	3.33E+04	4.21E+03	2.13E+01	3.80E+05	1.21E+06	
Aggregate, Crushed	Street AB[3]	1.77E+04	3.14E+03	6.75E+00	2.73E+05	0.00E+00	
PCC	Curb & Gutter Surface	1.38E+04	1.28E+03	7.57E+00	1.07E+05	0.00E+00	
Aggregate, Crushed	Curb & Gutter AB	1.17E+03	2.07E+02	4.45E-01	1.80E+04	0.00E+00	
Planting	Landscape	1.91E+01	1.07E+01	6.56E-02	7.71E+02	0.00E+00	
PCC	Sidewalk Surface	1.39E+04	1.29E+03	7.63E+00	1.08E+05	0.00E+00	
Aggregate, Crushed	Sidewalk AB	1.95E+03	3.45E+02	7.42E-01	3.00E+04	0.00E+00	
Total (Conventional Street Impacts)		*8.08E+04*	*1.03E+04*	*4.39E+01*	*8.97E+05*	*1.16E+06*	

[1] PCC = Portland cement concrete

[2] AB = Aggregate base

[3] HMA = Hot mix asphalt

Table 88 summarizes the absolute values of impact categories before (conventional street) and after (complete street) constructing the complete street for materials, transportation, and construction stages. Table 89 depicts the absolute change and the percentage change in each impact category when changing from the conventional street to the complete street.

Table 88. Summary of the Absolute Values of Impact Categories Before (Conventional Street) and After (Complete Street) the Construction of San Fernando Complete Street for Materials, Transportation, and Construction Stages.

Item	Functional Unit	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]
Total Impacts of the Conventional Street	1 Block	8.19E+04	1.05E+04	4.45E+01	9.17E+05	1.21E+06
Impacts of the Complete Street Elements of Complete Street	*1 Block*	*3.99E+03*	*4.08E+02*	*2.15E+00*	*3.45E+04*	*8.22E+03*
Impacts of the Conventional Elements of Complete Street	*1 Block*	*8.08E+04*	*1.03E+04*	*4.39E+01*	*8.97E+05*	*1.16E+06*
Total Impacts of the Complete Street	1 Block	8.48E+04	1.07E+04	4.61E+01	9.32E+05	1.16E+06

Table 89. Absolute and Percent changes in Material and Construction Stages Impact Indicators for San Fernando Street due to complete street implementation compared to the conventional options over the analysis period of 30 years

Item	Functional Unit	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]
Absolute Change (CS-Conv)	1 Block	2.89E+03	1.99E+02	1.53E+00	1.53E+04	-4.44E+04
% Change [(CS-Conv)/Conv]	1 Block	3.5%	1.9%	3.4%	1.7%	-3.7%

The changes between the complete street and the conventional street are due to different quantities used for different materials, primarily asphalt, concrete, and aggregate base resulting from the reduction in total pavement surface area in the complete street design. An increase of up to 4% was seen in all the impact categories except for the PED (non-fuel) indicator, where almost a 4% reduction was observed. A small increase of no more than 4% impacts indicates that converting a conventional street to a complete street may not be an environmental impact-intensive process compared to the benefits one attains from the complete streets. Reduction in PED (non-fuel) is the only category that demonstrates decreased impacts when transferring to complete street options, and occurs because less asphalt is used. As mentioned, PED (Non-Fuel) has no environmental impact and is a measure of using a non-renewable resource (oil). Also, note that an increase or decrease in the environmental impacts when converting from conventional streets to complete streets is project-specific. Every project is unique and may or may not have all features of the complete street, depending on the design. Therefore, each complete street project needs to be studied separately. The case study results presented in this report and in the previous report (Harvey et al., 2018) provide a general indication

Franklin Boulevard Case Study

The input used to quantify the environmental impacts for the Franklin Boulevard complete street case study is presented in Table 90. Table 91 and Table 93 show the needed information to calculate the itemized impacts during the 30 years analysis period for conventional options and complete street options, respectively. Table 92 and Table 94 present the impact categories of the Franklin Boulevard case study from the material, transportation, and construction stages (absolute values) before and after building the complete street, respectively.

Table 90. Inputs needed for Franklin Boulevard Complete Street Case study

Case Study	Block Length (m)	Complete Street Pavement Width (m)	Daily Traffic (#Cars/Day)	% Change in Emission Rates	Min. AB[2] Thickness (cm)	Min. HMA[3] Thickness (cm)	Vehicle Speed on the Street (km/h)
Franklin Boulevard	104	12.80	16,200	0.0%	33	8.89	56

[1] VMT = Vehicle miles traveled

[2] AB = Aggregate base

[3] HMA = Hot mix asphalt

Table 91. Input Needed for the Conventional Options to Calculate the Itemized Impacts for Materials, Transportation, and Construction Stages- Franklin Boulevard

Treatment (during the analysis period)	Functional Unit	Service Life [yrs]	Thick-ness (cm)	# of Treatment Application	Salvage (% of Service Life)	Traveled Way Width (m)	# per block	Note
HMA[1] (overlay)	1 Block	10.0	8.9	3	0%	3.70	3	Street Top Layer
Aggregate, Crushed	1 Block	15.0	33.0	2	0%	3.70	3	Street AB
PCC[2]	1 Block	20.0	15.2	2	50%	0.91	2	Curb & Gutter Surface
Aggregate, Crushed	1 Block	15.0	15.2	2	0%	0.91	2	Curb & Gutter AB
Planting	1 Block	5.0	NA	6	0%	1.83	2	Landscape
PCC	1 Block	20.0	9.2	2	50%	1.52	2	Sidewalk Surface
Aggregate, Crushed	1 Block	15.0	15.2	2	0%	1.52	2	Sidewalk AB

[1] HMA = Hot mix asphalt

[2] PCC = Portland cement concrete

Table 92. Absolute Values of Impact Categories for the Conventional Options for Materials, Transportation, and Construction Stages- Franklin Boulevard

Treatment (during the analysis period)	Functional Unit	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]	Share of this item in Total GWP
HMA[1] (overlay)	1 Block	4.27E+04	5.40E+03	2.73E+01	4.88E+05	1.55E+06	40.6%
Aggregate, Crushed	1 Block	2.27E+04	4.03E+03	8.67E+00	3.50E+05	0.00E+00	21.6%
PCC[2]	1 Block	1.78E+04	1.64E+03	9.72E+00	1.37E+05	0.00E+00	16.9%
Aggregate, Crushed	1 Block	1.50E+03	2.65E+02	5.71E-01	2.31E+04	0.00E+00	1.4%
Planting	1 Block	2.45E+01	1.38E+01	8.41E-02	9.90E+02	0.00E+00	0.0%
PCC	1 Block	1.79E+04	1.65E+03	9.79E+00	1.38E+05	0.00E+00	17.0%
Aggregate, Crushed	1 Block	2.50E+03	4.42E+02	9.52E-01	3.85E+04	0.00E+00	2.4%
Total	**1 Block**	**1.05E+05**	**1.34E+04**	**5.71E+01**	**1.18E+06**	**1.55E+06**	

[1] HMA = Hot mix asphalt

[2] PCC = Portland cement concrete

Table 93. Inputs needed for the Complete Street Options to Calculate the Itemized Impacts for Materials, Transportation, and Construction Stages- Franklin Boulevard

CS Element	Material	Service Life (yrs)	# per Block	Length (m)	Width (m)	Area of the Element (m2)	% of area that is replacing conventional treatment
Coloring Lanes	Paint (area)	3	2	104	2.13	221	0%
Shelter/Transit station	PCC[1] on AB[2]	15	1	15	3.00	45	100%
Planted Furniture Zone	Planting	5	1	84	2.00	167	100%
Curb Type 5	PCC	15	1		NA	NA	0%
Coloring Lanes	Paint (area)	3	2			0	0%
Raised Bicycle Buffer	HMA[3] (overlay)	10	2	104	NA	NA	0%
Buffered Cycle Track	HMA (overlay)	3	2	104	0.61	63	100%

[1] PCC = Portland cement concrete

[2] AB = Aggregate base

[3] HMA = Hot mix asphalt

Table 94 shows the breakdown of total GWP between the conventional elements and complete street elements. According to this table, 96% of the total GWP in the material, transportation, and construction stages belongs to the conventional elements, including the pavement, curbs, gutters, etc. On the other hand, only 4% of the total GWP belongs to the complete street elements.

Table 94. Absolute Values of Impact Categories for the Complete Street (After the CS Construction) for Materials, Transportation, and Construction Stages- Franklin Boulevard

CS Element	Material	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]	Share of this item in Total GWP
Complete Street Options							
Coloring Lanes	Paint (area)	7.60E-03	9.35E-02	6.95E-07	1.23E-02	0.00E+00	3.8%
Shelter/Transit station	PCC on AB	3.75E+03	3.77E+02	1.99E+00	3.17E+04	0.00E+00	
Planted Furniture Zone	Planting	1.08E+01	2.25E+00	1.37E-02	1.62E+02	0.00E+00	
Curb Type 5	PCC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Coloring Lanes	Paint (area)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
Raised Bicycle Buffer	HMA (overlay)	2.90E+02	3.67E+01	1.86E-01	3.32E+03	1.05E+04	
Buffered Cycle Track	HMA (overlay)	6.51E-04	8.01E-03	5.95E-08	1.05E-03	0.00E+00	
Total (for 1 Block)		*4.05E+03*	*4.16E+02*	*2.19E+00*	*3.52E+04*	*1.05E+04*	
Conventional Options							
Treatment (during the analysis period)	**Note**	**GWP [kg CO2e]**	**POCP [kg O3e]**	**PM2.5 [kg]**	**PED (Total) [MJ]**	**PED (Non-Fuel) [MJ]**	96.2%
HMA (overlay)	Street Top Layer	4.27E+04	5.40E+03	2.73E+01	4.88E+05	1.55E+06	
Aggregate, Crushed	Street AB	2.27E+04	4.03E+03	8.67E+00	3.50E+05	0.00E+00	
PCC	Curb & Gutter Surface	1.78E+04	1.64E+03	9.72E+00	1.37E+05	0.00E+00	
Aggregate, Crushed	Curb & Gutter AB	1.50E+03	2.65E+02	5.71E-01	2.31E+04	0.00E+00	
Planting	Landscape	2.45E+01	1.38E+01	8.41E-02	9.90E+02	0.00E+00	
PCC	Sidewalk Surface	1.79E+04	1.65E+03	9.79E+00	1.38E+05	0.00E+00	
Aggregate, Crushed	Sidewalk AB	2.50E+03	4.42E+02	9.52E-01	3.85E+04	0.00E+00	
Total (for 1 Block)		*1.04E+05*	*1.32E+04*	*5.65E+01*	*1.16E+06*	*1.50E+06*	

Table 95 summarizes the absolute values of impact categories before (conventional street) and after (complete street) constructing the complete street for materials, transportation, and construction stages. Table 96 depicts the absolute and percentage changes in each impact category when transferring from the conventional street to the complete street.

Table 95. Summary of the Absolute Values of Impact Categories Before (Conventional Street) and After (Complete Street) the Construction of Franklin Complete Street for Materials, Transportation, and Construction Stages.

Item	Functional Unit	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]
Total Impacts of the Conventional Street	1 Block	1.05E+05	1.34E+04	5.71E+01	1.18E+06	1.55E+06
Impacts of the CS Elements of Complete street	*1 Block*	*4.05E+03*	*4.16E+02*	*2.19E+00*	*3.52E+04*	*1.05E+04*
Impacts of the Conventional Elements of Complete street	*1 Block*	*1.04E+05*	*1.32E+04*	*5.65E+01*	*1.16E+06*	*1.50E+06*
Total Impacts of the Complete Street	1 Block	1.08E+05	1.36E+04	5.87E+01	1.19E+06	1.51E+06

Table 96. Absolute and Percent changes in Material and Construction Stages in Franklin Boulevard due to complete street implementation compared to the conventional options over the analysis period of 30 years

Item	Functional Unit	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]
Absolute Change (CS-Conv)	1 Block	2.95E+03	2.07E+02	1.57E+00	1.61E+04	-4.20E+04
% Change [(CS-Conv)/Conv]	1 Block	2.8%	1.5%	2.7%	1.4%	-2.7%

These changes between the complete street and the conventional street are due to different quantities used for different materials, primarily asphalt, concrete, and aggregate base resulting from the reduction in total pavement surface area in the complete street design. The changes in all the impact indicators are less than 3%, indicating that the conversion to a complete street leads to small changes in the amounts and types of materials used in a complete street compared to a conventional street. PED (Non-Fuel) is the only category that demonstrates decreased impacts when transferring to complete street options. This decrease is mostly because complete street elements replaced the asphalt pavement elements, with high PED (Non-Fuel) values, with other items. As mentioned, PED (Non-Fuel) has no environmental impact and measures the use of a non-renewable resource (oil).

Kentucky Avenue Case study

As discussed in the previous sections regarding the Kentucky Avenue case study, this complete street project widened Kentucky Avenue from two to four lanes from East Street to College Street and reconstructed the roadway as a complete street from East Street to West Street, including East Street to College Street and College Street to West Street.

The input used to calculate the environmental impacts for the Kentucky Avenue are presented in Table 97. Table 98 and Table 100 show the needed information to calculate the itemized impacts during the 30 years analysis period for the conventional options and complete street options, respectively. Table 99 and Table 101 represent the impact categories of the Kentucky Avenue case study from the material, transportation, and construction stages (absolute values) before and after building the complete street, respectively.

Table 97. Input needed for Kentucky Avenue Complete Street Case study

Case Study	**Block Length (m)**	**Complete Street Pavement Width (m)**	**Daily Traffic (#Cars/Day)**	**% Change in Emission Rates**	**Min AB[2] Thickness (cm)**	**Min HMA[3] Thickness (cm)**	**Vehicle Speed on the Street (km/h)**
West Kentucky Avenue	270	9.75	11635	0.0%	25.4	8.9	64.38
East Kentucky Avenue	270	12.80	11635	0.0%	33.0	7.62	64.38

[1] VMT = Vehicle miles traveled

[2] AB = Aggregate base

[3] HMA = Hot mix asphalt

Table 98. Input required for the Conventional Options to Calculate the Itemized Impacts for Materials, Transportation, and Construction Stages- Kentucky Avenue

	Treatment (during the analysis period)	Func-tional Unit	Service Life (yrs)	Thick-ness (cm)	# of Treat-ment Applica-tion	Salvage (% of Service Life)	Traveled Way Width (m)	# per block	Note
West Kentucky	HMA[1] (overlay)	1 Block	10.0	8.9	3	0%	3.70	3	Street Top Layer
	Aggregate, Crushed	1 Block	15.0	25.4	2	0%	3.70	3	Street AB[3]
	PCC[2]	1 Block	20.0	15.2	2	50%	0.91	2	Curb & Gutter Surface
	Aggregate, Crushed	1 Block	15.0	15.2	2	0%	0.91	2	Curb & Gutter AB
	Planting	1 Block	5.0	NA	6	0%	1.83	2	Landscape
	PCC	1 Block	20.0	9.2	2	50%	1.52	2	Sidewalk Surface
	Aggregate, Crushed	1 Block	15.0	15.2	2	0%	1.52	2	Sidewalk AB
	Total	**1 Block**							
East Kentucky	HMA (overlay)	1 Block	10.0	7.6	3	0%	3.70	3	Street Top Layer
	Aggregate, Crushed	1 Block	15.0	33.0	2	0%	3.70	3	Street AB
	PCC	1 Block	20.0	15.2	2	50%	0.91	2	Curb & Gutter Surface
	Aggregate, Crushed	1 Block	15.0	15.2	2	0%	0.91	2	Curb & Gutter AB
	Planting	1 Block	5.0	NA	6	0%	1.83	2	Landscape
	PCC	1 Block	20.0	9.2	2	50%	1.52	2	Sidewalk Surface
	Aggregate, Crushed	1 Block	15.0	15.2	2	0%	1.52	2	Sidewalk AB
	Total	**1 Block**							

[1] HMA = Hot mix asphalt

[2] PCC = Portland cement concrete

[3] AB = Aggregate base

Table 99. Absolute Values of Impact Categories for the Conventional Options for Materials, Transportation, and Construction Stages- Kentucky Avenue

	Treatment (during the analysis period)	**Func-tional Unit**	**GWP [kg CO2e]**	**POCP [kg O3e]**	**PM2.5 [kg]**	**PED (Total) [MJ]**	**PED (Non-Fuel) [MJ]**	**Share of this item in Total GWP[3]**
West Kentucky	HMA[1] (overlay)	1 Block	8.47E+04	1.07E+04	5.43E+01	9.68E+05	3.08E+06	38.0%
	Aggregate, Crushed	1 Block	3.47E+04	6.15E+03	1.32E+01	5.35E+05	0.00E+00	15.6%
	PCC[2]	1 Block	4.63E+04	4.28E+03	2.53E+01	3.57E+05	0.00E+00	20.8%
	Aggregate, Crushed	1 Block	3.90E+03	6.91E+02	1.49E+00	6.02E+04	0.00E+00	1.8%
	Planting	1 Block	6.39E+01	3.59E+01	2.19E-01	2.58E+03	0.00E+00	0.0%
	PCC	1 Block	4.66E+04	4.31E+03	2.55E+01	3.60E+05	0.00E+00	20.9%
	Aggregate, Crushed	1 Block	6.51E+03	1.15E+03	2.48E+00	1.00E+05	0.00E+00	2.9%
	Total	**1 Block**	**2.23E+05**	**2.73E+04**	**1.23E+02**	**2.38E+06**	**3.08E+06**	
East Kentucky	HMA (overlay)	1 Block	9.53E+04	1.21E+04	6.11E+01	1.09E+06	3.46E+06	38.1%
	Aggregate, Crushed	1 Block	5.14E+04	9.09E+03	1.96E+01	7.92E+05	0.00E+00	20.5%
	PCC	1 Block	4.63E+04	4.28E+03	2.53E+01	3.57E+05	0.00E+00	18.5%
	Aggregate, Crushed	1 Block	3.90E+03	6.91E+02	1.49E+00	6.02E+04	0.00E+00	1.6%
	Planting	1 Block	6.39E+01	3.59E+01	2.19E-01	2.58E+03	0.00E+00	0.0%
	PCC	1 Block	4.66E+04	4.31E+03	2.55E+01	3.60E+05	0.00E+00	18.6%
	Aggregate, Crushed	1 Block	6.51E+03	1.15E+03	2.48E+00	1.00E+05	0.00E+00	2.6%
	Total	**1 Block**	**2.50E+05**	**3.16E+04**	**1.36E+02**	**2.76E+06**	**3.46E+06**	

[1] HMA = Hot mix asphalt

[2] PCC = Portland cement concrete

Table 100. Inputs needed for the Complete Street Options to Calculate the Itemized Impacts for Materials, Transportation, and Construction Stages- Kentucky Avenue

	CS Element	Material	Service Life (yrs)	# per Block	Length (m)	Width (m)	Area of the Element (m2)	% of area that is replacing conventional treatment	Total Mass/ Area/ Length/ Count over that of the CS element in the CS tab
West Kentucky	Coloring Lanes	Paint (area)	3	1	270	2.13	576	0%	576
	Curb Extension	PCC[1] on AB[2]	15	3	8	2.44	20	100%	59
	Raising the Intersection to Sidewalk Grade	HMA (overlay)	10	1	10	3.00	29	0%	29
	Raised Bicycle Buffer	HMA (overlay)	10	2	8	NA	NA	0%	16
	Buffered Cycle Track	HMA[3] (overlay)	3	2	270	0.30	82	100%	165
	Total (for 1 Block)								
East Kentucky	Coloring Lanes	Paint (area)	3	2	270	2.13	576	0%	1152
	Planted Furniture Zone	Planting	5	1	250	2.00	500	100%	500
	Raised Bicycle Buffer	HMA (overlay)	10	2	270	NA	NA	0%	540
	Buffered Cycle Track	HMA (overlay)	3	2	270	0.30	82	100%	165
	Total (for 1 Block)								

[1] PCC = Portland cement concrete

[2] AB = Aggregate base

[3] HMA = Hot mix asphalt

Table 101 shows the breakdown of total GWP between the conventional elements and complete street elements for West Kentucky Avenue and East Kentucky Avenue. According to this table, 97% of the total GWP in the material, transportation, and construction stages comes from the conventional elements pavement, curbs, gutters, etc., in West Kentucky Avenue. At the same time, the share of the conventional part of East Kentucky Avenue is almost the whole GWP in the material and construction stage.

Table 101. Absolute Values of Impact Categories for the Complete Street (After the CS Construction) for Materials, Transportation, and Construction Stages- Kentucky Avenue

	CS Element	Material	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]	Share of this item in Total GWP
Complete Street Option								
West Kentucky	Coloring Lanes	Paint (area)	9.90E-03	1.22E-01	9.05E-07	1.60E-02	0.00E+00	2.6%
	Curb Extension	PCC[1] on AB[2]	4.88E+03	4.91E+02	2.59E+00	4.13E+04	0.00E+00	
	Raising the Intersection to Sidewalk Grade	HMA[3] (overlay)	1.08E+03	1.36E+02	6.89E-01	1.23E+04	3.91E+04	
	Raised Bicycle Buffer	HMA (overlay)	2.24E+01	2.83E+00	1.44E-02	2.56E+02	8.14E+02	
	Buffered Cycle Track	HMA (overlay)	8.48E-04	1.04E-02	7.76E-08	1.37E-03	0.00E+00	
	Total (for 1 Block)		*5.98E+03*	*6.30E+02*	*3.30E+00*	*5.38E+04*	*3.99E+04*	
East Kentucky	Coloring Lanes	Paint (area)	1.98E-02	2.44E-01	1.81E-06	3.20E-02	0.00E+00	0.3%
	Planted Furniture Zone	Planting	3.24E+01	6.73E+00	4.11E-02	4.83E+02	0.00E+00	
	Raised Bicycle Buffer	HMA (overlay)	7.56E+02	9.57E+01	4.85E-01	8.64E+03	2.75E+04	
	Buffered Cycle Track	HMA (overlay)	8.48E-04	1.04E-02	7.76E-08	1.37E-03	0.00E+00	
	Total Complete Street Impact (for 1 Block)		*7.88E+02*	*1.03E+02*	*5.26E-01*	*9.13E+03*	*2.75E+04*	
Conventional Option								
	Treatment (during the analysis period)	**Note**	**GWP [kg CO2e]**	**POCP [kg O3e]**	**PM2.5 [kg]**	**PED (Total) [MJ]**	**PED (Non-Fuel) [MJ]**	
West Kentucky	HMA (overlay)	Street Top Layer	8.47E+04	1.07E+04	5.43E+01	9.68E+05	3.08E+06	97.4%
	Aggregate, Crushed	Street AB[3]	3.47E+04	6.15E+03	1.32E+01	5.35E+05	0.00E+00	
	PCC	Curb & Gutter Surface	4.63E+04	4.28E+03	2.53E+01	3.57E+05	0.00E+00	
	Aggregate, Crushed	Curb & Gutter AB	3.90E+03	6.91E+02	1.49E+00	6.02E+04	0.00E+00	
	Planting	Landscape	6.39E+01	3.59E+01	2.19E-01	2.58E+03	0.00E+00	

	CS Element	**Material**	**GWP [kg CO2e]**	**POCP [kg O3e]**	**PM2.5 [kg]**	**PED (Total) [MJ]**	**PED (Non-Fuel) [MJ]**	**Share of this item in Total GWP**
	PCC	Sidewalk Surface	4.66E+04	4.31E+03	2.55E+01	3.60E+05	0.00E+00	
	Aggregate, Crushed	Sidewalk AB	6.51E+03	1.15E+03	2.48E+00	1.00E+05	0.00E+00	
	Total		*2.21E+05*	*2.70E+04*	*1.22E+02*	*2.36E+06*	*3.01E+06*	
East Kentucky	HMA (overlay)	Street Top Layer	1.11E+05	1.41E+04	7.12E+01	1.27E+06	4.04E+06	99.7%
	Aggregate, Crushed	Street AB	5.92E+04	1.05E+04	2.26E+01	9.13E+05	0.00E+00	
	PCC	Curb & Gutter Surface	4.63E+04	4.28E+03	2.53E+01	3.57E+05	0.00E+00	
	Aggregate, Crushed	Curb & Gutter AB	3.90E+03	6.91E+02	1.49E+00	6.02E+04	0.00E+00	
	Planting	Landscape	6.39E+01	3.59E+01	2.19E-01	2.58E+03	0.00E+00	
	PCC	Sidewalk Surface	4.66E+04	4.31E+03	2.55E+01	3.60E+05	0.00E+00	
	Aggregate, Crushed	Sidewalk AB	6.51E+03	1.15E+03	2.48E+00	1.00E+05	0.00E+00	
	Total Conventional Street Impact	*1 Block*	*2.74E+05*	*3.50E+04*	*1.49E+02*	*3.06E+06*	*4.04E+06*	

[1] PCC = Portland cement concrete

[2] AB = Aggregate base

[3] HMA = Hot mix asphalt

Table 102 summarizes the absolute values of impact categories before (conventional street) and after (complete street) the construction of complete street for materials, transportation, and construction stages for West Kentucky Avenue and East Kentucky Avenue. Table 103 shows the absolute change and the percentage change in each impact category when transferring from the conventional street to the complete street for West and East Kentucky Avenue.

Table 102. Summary of the Absolute Values of Impact Categories Before (Conventional Street) and After (Complete Street) the Construction of Kentucky Avenue Complete Street for Materials, Transportation, and Construction Stages

	Item	Functional Unit	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]
West Kentucky	**Total Impacts of the Conventional Street**	*1 Block*	*2.23E+05*	*2.73E+04*	*1.23E+02*	*2.38E+06*	*3.08E+06*
	Impacts of the CS Elements of Complete street	*1 Block*	*5.98E+03*	*6.30E+02*	*3.30E+00*	*5.38E+04*	*3.99E+04*
	Impacts of the Conventional Elements Elements of Complete street	*1 Block*	*2.21E+05*	*2.70E+04*	*1.22E+02*	*2.36E+06*	*3.01E+06*
	Total Impacts of the Complete Street	1 Block	2.27E+05	2.77E+04	1.25E+02	2.41E+06	3.05E+06
East Kentucky	**Total Impacts of the Conventional Street**	*1 Block*	*2.50E+05*	*3.16E+04*	*1.36E+02*	*2.76E+06*	*3.46E+06*
	Impacts of the CS Elements of Complete street	*1 Block*	*7.88E+02*	*1.03E+02*	*5.26E-01*	*9.13E+03*	*2.75E+04*
	Impacts of the Conventional Elements Elements of Complete street	*1 Block*	*2.58E+05*	*3.30E+04*	*1.39E+02*	*2.88E+06*	*3.46E+06*
	Total Impacts of the Complete Street	1 Block	*2.59E+05*	*3.31E+04*	*1.39E+02*	*2.89E+06*	*3.49E+06*

Table 103. Absolute and Percent in Material and Construction Stages Change changes in Kentucky Avenue due to complete street implementation compared to the conventional options over the analysis period of 30 years

	Item	Functional Unit	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]
West Kentucky	Absolute Change (CS-Conv)	1 Block	4.23E+03	3.45E+02	2.28E+00	2.80E+04	- 2.85E+04
	% Change [(CS-Conv)/Conv]	1 Block	1.9%	1.3%	1.9%	1.2%	-0.9%
East Kentucky	Absolute Change (CS-Conv)	1 Block	8.66E+03	1.50E+03	3.53E+00	1.30E+05	2.75E+04
	% Change [(CS-Conv)/Conv]	1 Block	3.5%	4.7%	2.6%	4.7%	0.8%

These changes between the complete street and the conventional street are due to differences in the quantities used for different types of materials, primarily asphalt, concrete, and aggregate base resulting from the reduction in total pavement surface area in the complete street design. Changes in all the impact indicators are less than 2% for West Kentucky Avenue, and less than 5% for East Kentucky Avenue. These small changes indicate that converting a conventional street to a complete street may not be an environmental impact-intensive process compared to the benefits one attains from the complete streets. Reduction in PED (non-fuel) is the only category in West Kentucky Avenue. that demonstrates a decrease in impacts when transferring to complete street options, which is mostly because complete street elements replaced the asphalt pavement elements, with high PED (Non-Fuel) values, with other items. As mentioned, PED (Non-Fuel) has no environmental impact and is a measure of using a non-renewable resource (oil).

Summary of Conventional and Complete Street Elements Infrastructure Delivery Contributions to GHG

The contributions of the conventional street elements and the additional complete streets elements to the total GHG emissions for each project are summarized in see Figure 34. In all cases, the contribution of the complete streets elements is less than 5% of the total emissions.

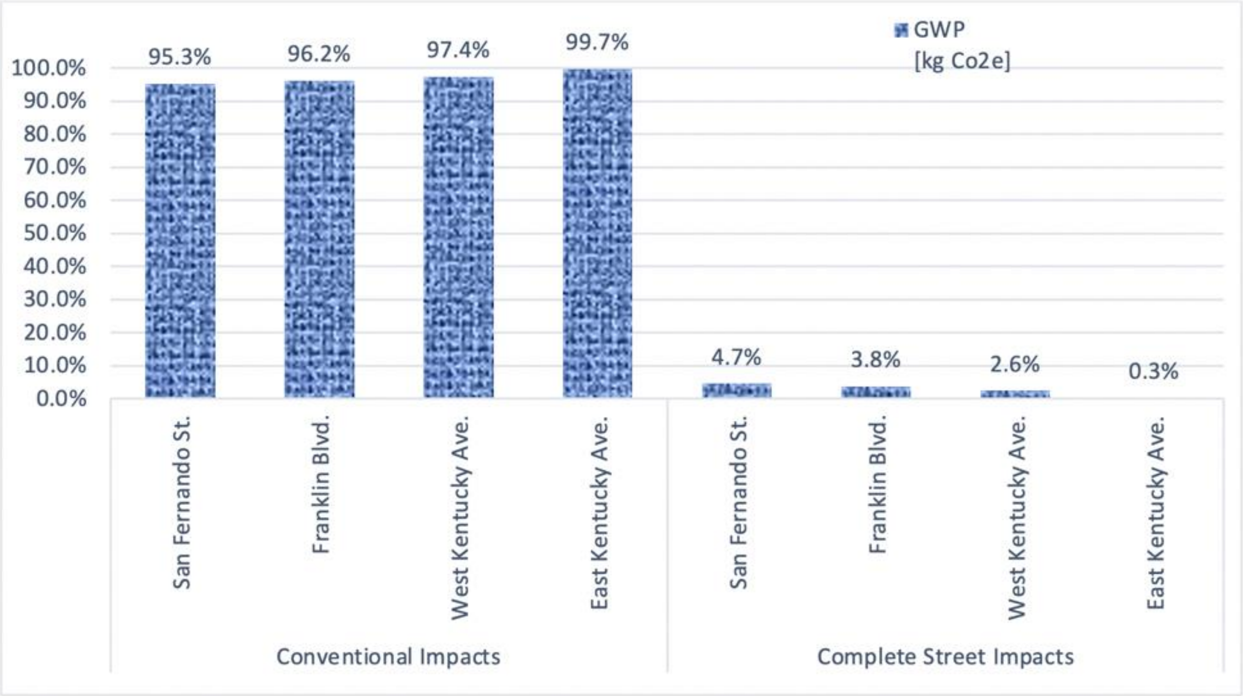

Figure 34. Breakdown of materials and construction GWP of complete streets between their conventional elements and complete street elements

Change in Vehicle Miles Travelled (VMT) and Traffic Speed

One of the primary goals of the complete street design guidelines is to reduce VMT by facilitating active transportation, including walking and bicycling modes. Reducing traffic speeds with complete streets features can improve active transportation safety and potentially to transfers of motorized vehicle mode to the active mode of transportation; however, reduced speeds can negatively impact the vehicle fuel efficiencies. The analysis in this section was performed to quantify the environmental impacts due to change in the VMT and speed change before and after the construction of complete streets, combined with the LCA results from materials, transportation, and construction stages shown in the previous section. The relative sensitivities of materials, transportation, and construction stages, speed change, and VMT change on the model outputs are analyzed in this section.

Following the LCA framework for complete streets (Harvey et al., 2018), the environmental impacts of fuel combustion in vehicles during the use stage were used to evaluate the emissions due to changes in VMT before and after the construction of the complete streets. There are associated information and related assumptions for each case study, mostly based on the framework, including the environmental impacts of fuel consumption calculated in two separate stages: a) gasoline production (well-to-pump) and b) tailpipe emissions (pump-to-wheel).

Gasoline production encompasses all the upstream impacts, including crude oil extraction, transportation to the refinery plant, processes performed at the refinery, and transportation to the filling station. These data were collected from the GaBi software (GaBi 2019).

The combustion of fuel by the vehicle results in tailpipe emissions. Following the framework's assumptions, the EMFAC web database developed by the California Air Resources Board was used in this stage (EMFAC Web Database). Then, the emission rates of light-duty autos (passenger cars) and light-duty truck type 1 (sports utility vehicles [SUV] and pick-ups) vehicles in Sacramento County in 2018 were extracted and used for the case studies. 60% of the vehicles were assumed to be passenger cars, and 40% were assumed to be light-duty trucks. Changes in VMT of freight vehicles and buses were not considered in this study. Only constant speeds were considered in the modeling, and changes in the drive cycles were not included because EMFAC does not have detailed drive cycle data. Two design speeds were considered before and after the construction of the complete streets.

Table 104 shows the traffic volume and speed for each case study. Changes in VMT were calculated using the California Air Resource Board VMT reduction tool (CARB, 2016).

Table 104. Inputs for Calculating the Vehicle Fuel Consumptions for San Fernando Street, Franklin Boulevard, and Kentucky Avenue Case Studies

Case Study	Daily Traffic (#Cars/Day)	Estimated % Change in VMT after Complete Street is built	Conventional Design Speed (mph)	Complete Street Design Speed (mph)
San Fernando Street	9,957	-1.1%	25	25
Franklin Boulevard	16,200	-1.4%	35	30
Kentucky Avenue	11,635	-2.2%	40	35

Table 105 summarizes the LCIA results during the use stage for the three case studies evaluating the traffic emissions a) before building the complete streets (conventional design or Conv), b) after construction of the complete streets (complete street design (ΔVMT)) considering only VMT changes, and c) after construction of the complete streets (complete street design (ΔVMT + Speed Change)) considering both VMT changes and speed changes.

Table 105. LCIA results during the use stage evaluating the traffic emissions in the conventional situation, complete street situation (considering change in VMT), and complete street situation (considering change in VMT and speed) for the three case studies

Item	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]
San Fernando Street				
Traffic (Conv[a])	2.46E+06	1.26E+02	2.54E+04	3.16E+07
Traffic (CS[b]+ΔVMT[c])	2.43E+06	1.25E+02	2.51E+04	3.13E+07
Traffic (CS+ΔVMT+Speed Change)	2.43E+06	1.25E+02	2.51E+04	3.13E+07
Franklin Boulevard				
Traffic (Conv)	4.28E+06	2.31E+02	4.65E+04	5.79E+07
Traffic (CS+ΔVMT)	4.22E+06	2.28E+02	4.59E+04	5.71E+07
Traffic (CS+ΔVMT+Speed Change)	4.64E+06	2.44E+02	4.91E+04	6.11E+07
Kentucky Avenue				
Traffic (Conv)	7.81E+06	4.08E+02	8.19E+04	1.02E+08
Traffic (CS+ΔVMT)	7.64E+06	3.98E+02	8.01E+04	9.97E+07
Traffic (CS+ΔVMT+Speed Change)	7.83E+06	4.23E+02	8.51E+04	1.06E+08

[a] *Conv: Conventional design (before the construction of the complete street)*

[b] *CS: Complete street design (After the construction of the complete street)*

[c] *ΔVMT: Change in the VMT (After the construction of the CS – Before the construction of the CS)*

Figure 35 to Figure 38 present the changes in LCIA results during different stages, including the change in material, transportation, and construction stage based on the previous sections and use stage (the change in VMT and change in both VMT and speed). Based on the results shown in Figure 35 through Figure 38, reductions in traffic speed can significantly impact the well-to-wheel emissions of the traffic during the use stage. Reducing design speeds from 56 to 48 km/h

(35 to 30 mph) on Franklin Boulevard and 64 to 56 km/h (40 to 35 mph) on Kentucky Avenue increase well-to-wheel impacts for the complete street versus conventional options across their VMT changes. Franklin Boulevard shows a sharp increase in the GWP when both speed and VMT are changed (Figure 35). Because, within the speed range of residential parts of this street, any speed reduction results in dramatic decreases in fuel efficiency and increases in tailpipe emissions, and the resulting increased emissions cannot be offset by a 1% to 2% reduction in VMT of this case study.

Changes in speed and VMT on Franklin Boulevard leads to a large increased in emissions and on Kentucky Avenue to a slight increase in all the impact categories. However, a small decrease in the impacts was observed for the San Fernando complete street project as no speed change on the San Fernando Street was made. In contrast, a reduction across all impact categories was seen for all the three case studies when VMT was changed but the speed was not. It is important to note that heavy vehicles such as freight trucks are not included in the analysis as these streets are not truck traffic intensive.

According to Figure 35 through Figure 38 changes in the material and construction stages are negligible compared to the use phase for all three case studies. The results from these three case studies indicate that the effects on environmental impacts due to a complete street implementation should be analyzed separately and on a project-by-project basis. They also indicate that additional reductions in VMT of around 5% that might be expected as complete street networks begin to connect and increase the viability of active transportation trips could result in overall decreases in emissions.

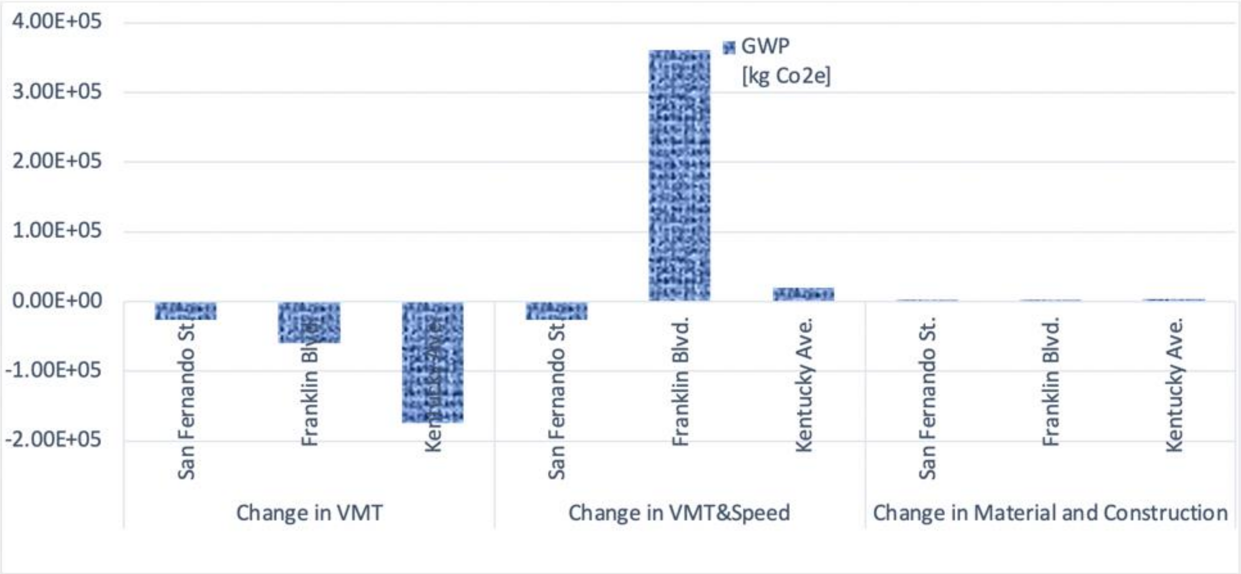

Figure 35. The difference in Well-to-Wheel and Material and Construction GWP [kg CO2e] Impacts (CS-Conv) during the Analysis Period (30 years) for the three case studies

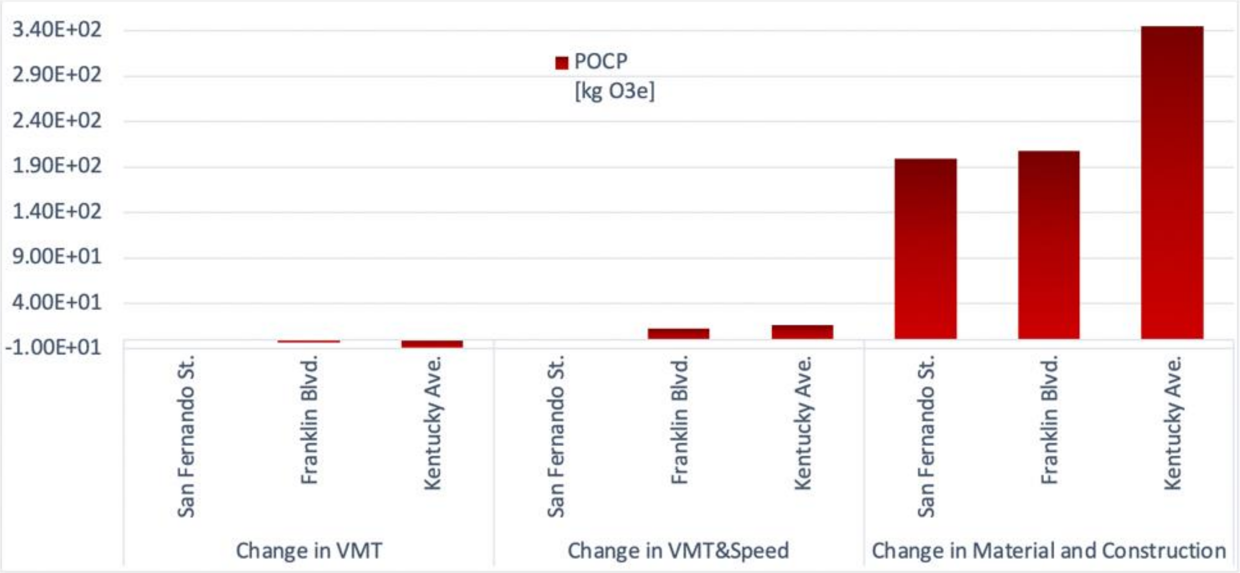

Figure 36. The difference in Well-to-Wheel and Material and Construction POCP [kg O3e] Impacts (CS-Conv) during the Analysis Period (30 years) for the three case studies

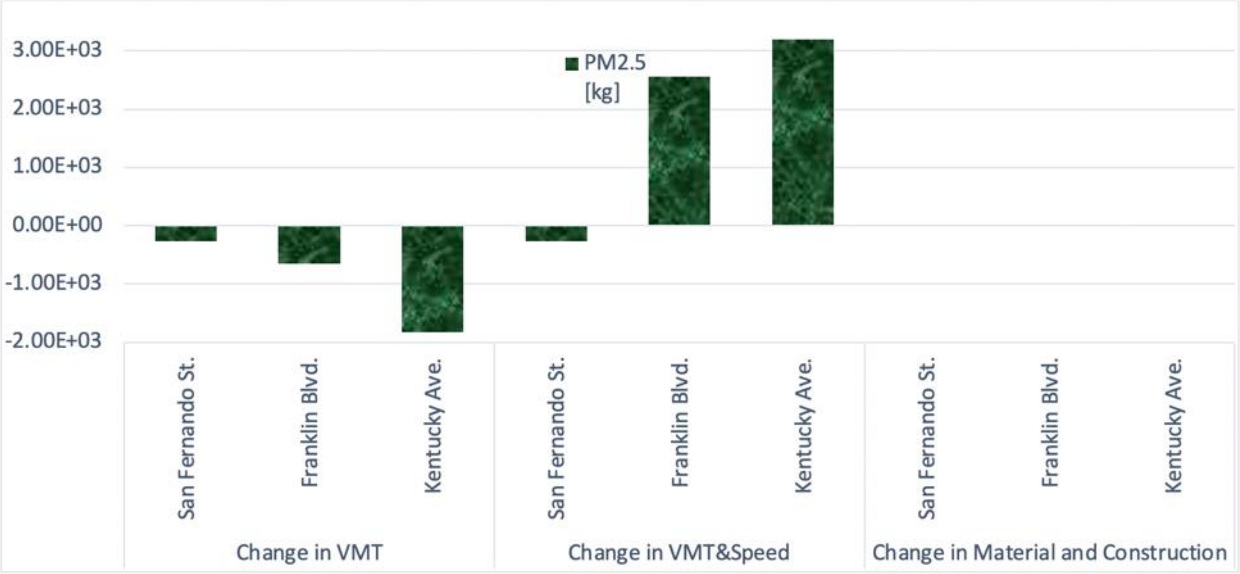

Figure 37. The difference in Well-to-Wheel and Material and Construction PM2.5 [kg] Impacts (CS-Conv) during the Analysis Period (30 years) for the three case studies

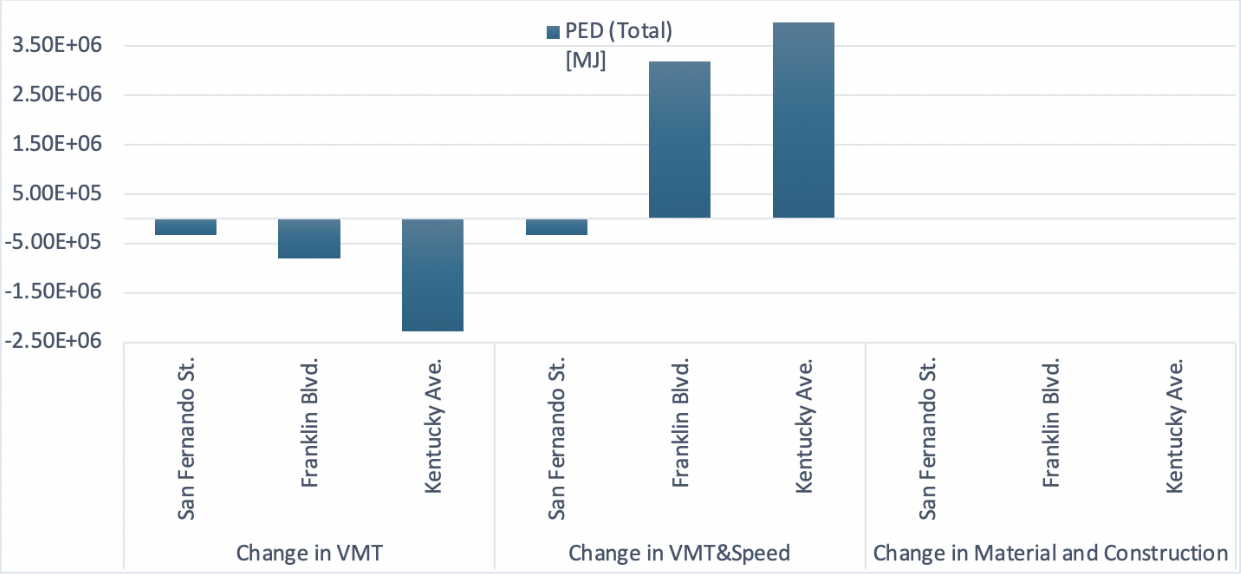

Figure 38. The difference in Well-to-Wheel and Material and Construction PED [MJ] Impacts (CS-Conv) during the Analysis Period (30 years) for the three case studies

Chapter 8: Summary of Results and Recommendations for Complete Streets LCA Framework

Summary

The goal of this project and its predecessor is to develop the methodology to quantitatively help answer this question: is a complete street a solution for a proposed project in the public street right-of-way to improve the functionality of shared spaces? If built or proposed but not yet built, how will the complete street deliver the intended performance with regard to safety, accessibility to all users, convenience, economic benefits, and environmental benefits and comfort as it was designed for that location and in that street network?" This question is important when determining how best to achieve these goals for a given neighborhood, what features to design into the proposed project, and where to locate projects.

Results of three case studies are presented in this report from quantifying the socio-economic and environmental impacts of complete streets and comparing them with the existing conventional streets, focusing primarily on the social performance indicators and also including environmental indicators. The results are compared with the conventional existing streets that were configured to be vehicle-centric. To test the framework, the three case studies were solicited in urban, suburban, and rural areas. The case studies also include more and less advantaged neighborhoods. Case study evaluation was based on the project design for those that had not yet been started or completed. Where the case study project had been completed, the project was evaluated based on performance before and after project completion.

The primary purpose of the case studies was to evaluate the efficacy of the performance measures proposed in the previous project with regard to reasonableness of the results and the practicalities and difficulties of using them with the intent to provide a recommended final set of indicators. The indicators were also tested for use in areas with more and less advantaged areas in terms of density of community destinations, access to transit, and population density. The second purpose was to evaluate complete streets in different contexts and see what kinds of benefits the indicators identified, and where the indicators did not identify benefits. The benefits were also considered with respect to social and environmental vulnerability and existing environmental, social and health burdens by inclusion of use of a social vulnerability indexing tool, in this case CalEnviroScreen. The third purpose was to advance the use of quantitative tools to help measure the success of a complete streets project to improve neighborhood quality of life by improving the ability to use active transportation and active transportation with transit as part of mobility to safely reach destinations of interest.

Conclusions

Evaluation of Social and Economic Performance Indicators

The social and economic performance indicators included in the social LCA (SLCA) framework that was used in this project provide insight into specific and different potential benefits of a given complete streets project. The SLCA framework is based on five categories of concerns and 17 performance measures or indicators. They span the range of benefits typically expressed as being desirable for a neighborhood, and potentially coming from a complete street. The case studies reinforced the observation when assembling the framework that all the performance indicators should be considered as set, rather than being converted into a simple score. According to the UNEP SLCA guidelines, aggregating and weighting can be used in the final steps of LCA, leading to a final SLCA score. However, the authors of this study believe that due to the context-specific and qualitative nature of social aspects of the complete streets, and the desire for different benefits from different projects, indicating only one SLCA final score does not portray the complete picture and may also be misleading.

The case studies also reconfirmed the idea of the original framework that the observed or estimated change direction for each indicator, the desired direction of change for each category and each indicator, and the size of the change are all important when considering the multiple effects of constructing a complete street. Examining the likely changes in these indicators from the complete street projects provided a more holistic view of the project and its likely benefits and disbenefits, or likely ineffectiveness in creating change, than would otherwise be possible. Although other benefits, such as a “sense of place” and neighborhood pride are not measurable, the majority of the expressed purposes for building a complete street can be evaluated. In particular, even if all complete streets projects provide benefits, the relative size of the changes in beneficial outcomes is now possible.

The performance indicators also provide a quantitative sense of locations where the complete street is likely not providing some benefits and/or where the design or location for the complete streets might be changed to do a better job of providing a particular type of benefit. Examples include the results from the survey of principals (although only two surveys were returned) that indicated the need for additional complete streets within the active transportation buffers for the Franklin Boulevard and Kentucky Avenue projects to provide additional benefits for safe access to their schools. They also show where the complete street by itself will provide impressive results for a given type of benefit. Examples include improved pedestrian level of service for Kentucky Avenue, and improvement of the bicycle level of stress and connectivity to transit for Franklin Boulevard and San Fernando Street.

The main challenges in this social LCA (SLCA) study were data collection and the inherent context-specific and qualitative nature of social aspects of each complete street project. Finding historical data for the complete streets that were already built, such as for the San Fernando Street and Kentucky Avenue case studies, was difficult or impossible for some indicators. For the complete street that has not yet been built, such as the Franklin Boulevard case study, it was hard to predict the outcome of the complete street project and what will data look like in the future. As with any work involving complex data gathering and calculations there is a steep learning curve, with more effort required earlier in the process, and greater productivity as experience is gained. It is expected that as quantitative measures become more commonplace for evaluating projects, efforts to improve data sources and methods for using the data will reduce the effort. Each indicator was rated by the data collectors for difficulty. It can be seen from the results of finding and interpreting the results of these case studies that further improvement of the Social LCA framework for complete streets to make it more efficient and practical should involve the following steps:

- The performance indicators should be reviewed for difficulty of data collection, difficulty of interpretation, and usefulness to providing data to support decision-making regarding where to locate and how to design complete streets
- The performance indicator review should include consideration of improvement of indicators for both data collection and interpretation
- The recommended indicators should be reduced to a minimum set sufficient to provide sufficient information to support decision-making to reduce the cost and time needed to complete an evaluation

The evaluations of performance measures have been interpreted and discussed for each case study separately. The results summary of all the performance measures quantified for the three case studies were presented in Table 78, Table 79, and Table 80. The following are the initial results of following the process bulleted above.

Access to schools is a very important indicator for most neighborhoods, however, there are interpretation issues with the Access to Schools indicator. Results from the two survey results from school principals indicated that this measure may not do a good job of capturing the impacts or lack of impacts of a complete street on travel to school because of particular travel-to-school patterns and challenges and/or the lack of a more built-out complete streets network. The results from the survey were illuminating and the use of this or a similar survey as part of evaluation of Access to School is recommended.

The Job Creation indicator was difficult to interpret. It uses a model that has uncertainty as to its ability to predict permanent and part-time jobs stimulated by the complete street. Since only a top-down model was found to be practical, and its results not particularly applicable for estimating the creation of permanent jobs, rather than jobs related to the design and construction of the complete street, it is recommended that this indicator be dropped. Instead, if job creation is an important priority for building complete streets, it is recommended that attention be paid to building complete streets in locations where planning and investment for the creation of new businesses or other types of permanent job creation will also occur. It is also recommended that more research be conducted on the synergistic interactions of complete streets and that kind of planning and investment for potential development of better job creation indicators.

Job retention is also important, potentially more important than job creation because existing businesses may be closely associated with employing and serving existing neighborhood residents. Retention of talented and young people to work in neighborhoods can potentially be aided by infrastructure investments such as complete streets. The framework currently has no indicator for this important consideration.

There was debate in this research regarding interpretation of the Bike/Pedestrian Delay indicator. Construction of a complete street can increase delay through changes in stop light timing, addition of stops signs, and other measures in the design that slow vehicle traffic, which is important for active transportation safety (particularly bicycle safety where there are on-street bicycle lanes), but which may also slow active transportation travel. Increases in delay that slow active transportation travel may reduce the desire of people using active transportation to quickly get to their destinations.

On the other hand, one of the purposes of a complete street is to provide active transportation access to multiple attractions (businesses, recreational activities, social interaction) along the complete street, which often be increased by slower travel. Complete streets are often part of strategies to change streets from high-speed traffic conveyors through neighborhoods to welcoming places that attract shoppers and residents by allowing them to easily cross the street and interact with small clusters of businesses or “nodes”. This is expected to lead to increased shopping and revenue, and job and business retention. Increasing transit stops along the complete street allows lower income people, who predominantly are those without cars, to access these nodes for activity and employment.

Interpretation of the delay indicator likely needs consideration of whether the complete street is intended as a safe connector between locations, or a safe and attractive way to produce social and economic activity at the location of the complete street through better access by active transportation.

Adding bicycle and pedestrian trip numbers in addition to BMT and PMT was suggested in this study to help the framework test and interpret whether BMT and PMT are indicating more active transportation or instead indicating long distances between sparse community destinations. The pedestrian level of service (PLOS) and bicycle level of service (BLOS) indicators are not recommended for continued inclusion because of the difficulty of using them, and the uncertainty of interpreting them. Better versions of PLOS and BLOS should be investigated for inclusion.

The current study did not consider physical activity and green land consumption indicators because collecting data for these performance measures was not doable due to the unavailability of data for the specific complete streets case studies.

Consideration of Complete Streets Indicators in Advantaged and Disadvantaged Neighborhoods

The three case studies were also used to evaluate each of the performance indicators as they were being used to evaluate complete streets in more and less advantaged neighborhoods. Disadvantaged neighborhoods are those that have had less public and private investment reflected by fewer community destinations, fewer schools, fewer jobs, and greater physical and social isolation from opportunities because of less physical connectivity. a complete street can have value in both affluent and segregated space. The lack of investment, destinations supporting opportunity and well-being, and connectivity is commonly due to past intentional segregation based on race as well as income.

Complete streets can benefit all kinds of neighborhoods, which is reflected in the final values for the indicators. Locations with many destinations of opportunity can be benefited by connecting them with complete street projects that help the neighborhood and build out the network of complete streets.

Disadvantaged neighborhoods (also called priority population areas) and/or more rural or rural/urban interface areas with a lower density destinations will not show final indicator values as high as more advantaged neighborhoods or neighborhoods with denser populations. These neighborhoods may show greater change in the calculated indicator if they have little current access by complete street compared with an advantaged neighborhood that already has some complete streets. Consideration of further investment to create more destinations in populated areas, particularly higher density of destinations on the complete street and both near housing, should be considered simultaneously with the complete street.

Urban/rural fringe areas may particularly benefit from placing complete streets to connect to schools even where there is a sparse density of other destinations. are discussed in the case study chapters of this report and are considered in the final recommendations for performance indicators.

There are concerns about the use and interpretation of the Pedestrian Miles Traveled (PMT) and Bicycle Miles Traveled (BMT) indicators. Higher values for these two indicators are generally considered to be indications of benefits. The concern is that high PMT and BMT numbers can be caused by a lack of schools, healthcare, stores, parks, jobs, and other destinations of interest within accessible walking, bicycling, or active transportation plus transit distances in or near a disadvantaged neighborhood. High PMT and BMT numbers might indicate the need for greater investment in destinations contributing to quality of life, rather than a positive active transportation environment. The inclusion of a Pedestrian Trips and a Bicycle Trips indicator along with PMT and BMT would provide a better indication of which is the case for a given project.

The authors believe that that quantification of complete streets social benefits using the SLCA framework facilitates these types of analysis and interpretation when planning and designing complete streets projects and complete streets networks. The use of the social vulnerability and current impact burdens with the SLCA framework provided additional important information for planning of complete streets and networks. For these case studies the CalEnviroScreen tool was used along with the performance indicators to help identify projects that particularly help neighborhoods where people are disadvantaged and bearing the burdens of inadequate existing transportation or existing transportation systems that damage their quality of life. In terms of serving disadvantaged neighborhoods, Franklin Boulevard had the highest CalEnviroScreen percentile score, indicating that it provided the most benefit to disadvantaged neighborhoods, followed by San Fernando Street and then Kentucky Avenue. The use of the CalEnviroScreen tool with the SLCA performance measures provides a very strong methodology for identifying which complete streets will provide the most benefit to the most disadvantaged communities. CalEnviroScreen is a reliable source for this type of data that doesn’t require aggregating use of census data. Others outside of California can replicate this model using data from the Center for Disease Control and Prevention’s Social Vulnerability Index (CDC SVI).

Environmental LCA

As was the case for the initial evaluation of the Complete Streets LCA Framework, the environmental impacts coming from the materials, materials transportation, and construction phases of building or reconstructing a conventional versus a compete street are very small. The coming of new LCA tools to easily calculate environmental impacts for materials, transportation, and construction will make the evaluation of design alternatives to reduce environmental impacts relatively easy.

The primary environmental impacts come from the use stage. Any changes in vehicle travel (vehicle miles traveled, VMT) will have a relatively large impact on environmental impacts as long as the vehicle fleet remains primarily dependent on internal combustion engines. The effects of reduction in vehicle speeds from complete street design features are somewhat more complex than they appear in the analysis in this report. Reductions in speed at speeds below 45 miles per hour may increase fuel use and emissions for longer blocks. This is an area that needs more detailed drive cycle study.

The effects of adding street trees were not considered in the environmental LCA. The extent of available modeling is not known but should be investigated in future studies.

Recommendations

Recommended and Not Recommended Performance Indicators for the SLCA Framework

The authors chose one or more performance measures from each category that were not too difficult in terms of data collection, methodology, and interpretation. The selected performance measures have lower scores (better ranks) and are easier to interpret compared to the unselected ones. Table 106 shows the degree of difficulty of data collection and use of the methodology for each performance measure in the initial framework, and the final recommended and not recommended performance measures, according to the three case studies. The reasons for difficulty in data collection, methodology, or interpretation for each performance measure were explained in each case study’s section and are summarized in Table 106.

Use of Social Vulnerability Data with the SLCA Framework Performance Indicators

The use of the CalEnviroScreen tool with the SLCA Framework for Complete Streets, or other data such as the federal Social Vulnerability Index, is recommended to provide quantitative assessment indicators for the social and health vulnerability and existing environmental burdens of neighborhoods in which complete streets projects are proposed to be built. This information helps identify neighborhoods that may have previous poor investment in community destinations (public and private) and transportation infrastructure and that may particularly benefit from better access using lower-cost active transportation, particularly when it is used to connect with transit. Use of this kind of data can also be used to help track that neighborhoods that have previously been disadvantaged because of segregation, discrimination and lack of public investment are receiving complete streets and other investments that can reduce social and health vulnerability and environmental burdens.

Overall Conclusions

The purpose of the project presented in this report was successfully achieved by the testing of the complete streets LCA framework developed in a previous project by using it to quantify the environmental and social impacts of complete streets through three case studies. The results were used to evaluate the efficacy of the performance measures proposed in the previous project regarding reasonableness of the results and the practicalities and difficulties of using them to provide a recommended final set of indicators. A new part of the framework is the use of social vulnerability information to help inform the process of quantitatively assessing the benefits of complete streets. The results and recommendations from the project will be used to further refine the social and environmental LCA framework to provide more useful quantitative decision support information and to make it easier to use. Table 106 shows the recommended and not recommended performance measures based on experience from the three case studies.

Table 106. Recommended (R) and Not Recommended (NR) Performance Measures Based on Experience from the Three Case Studies

Category	Performance Measure	Data Difficulty (1-5)	Methodology / Calculation Difficulty (1-5)	Analysis or Interpretation Issue (Yes or No)	Comments	Recommended (R) or Not Recommended (NR)
Accessibility	Access to Community Destinations	4	1	No	• Data collection was time-consuming due to number of destinations. • Collecting data before the construction of the complete street for San Fernando St. and Kentucky Ave. was difficult. • Collecting data for after the construction of the Franklin Blvd. complete street was difficult. • Interpretation of change of access should be for access by complete streets and should consider change of community destinations which may not be related to complete street.	R
	Access to school	5	3	Yes/ Interpretation	• Data collection was very difficult due to dependency on the school principals' responses. Use of the school survey developed for this project is recommended.	R
Jobs	Access to Jobs	4	1	No	• Data collection was time-consuming due to number of jobs. • Collecting data before the construction of the complete street for San Fernando St. and Kentucky Ave. was difficult. • Collecting data for after the construction of the Franklin Blvd. complete street was difficult. • Interpretation of change of access should be for access by complete streets and should consider estimated change of jobs which may not be related to complete street.	R

Category	Performance Measure	Data Difficulty (1-5)	Methodology / Calculation Difficulty (1-5)	Analysis or Interpretation Issue (Yes or No)	Comments	Recommended (R) or Not Recommended (NR)
	Job Creation	5	3	Yes/ Interpretation	• Collecting data for only the complete street project was very difficult, national model was used. • Collecting data for temporary and permanent jobs and distinguishing them was difficult, national model was used.	NR
Mobility/ Connectivity	Active Transportation to Local and Regional Transit Connectivity Index*	3	1	No	• Collecting data before the construction of the complete street for San Fernando St. and Kentucky Ave. was difficult. • Collecting data for after the construction of the Franklin Blvd. complete street was difficult.	R
	Connectivity Index	3	1	No	• Collecting data before the construction of the complete street for San Fernando St. and Kentucky Ave. was difficult. • Collecting data for after the construction of the Franklin Blvd. complete street was difficult.	R
	Bike/Pedestrian Delay	3	1	Yes/ Interpretation	• Collecting data before the construction of the complete street for San Fernando St. and Kentucky Ave. was difficult. • Collecting data for after the construction of the Franklin Blvd. complete street was difficult. • There is a debate regarding the positive and negative influences of delay on the functionality of the complete street. The goal of the complete street (through travel or destination travel) needs to be identified to interpret results.	R

Category	**Performance Measure**	**Data Difficulty (1-5)**	**Methodology / Calculation Difficulty (1-5)**	**Analysis or Interpretation Issue (Yes or No)**	**Comments**	**Recommended (R) or Not Recommended (NR)**
Safety/ Public Health	Level of Service (Bicycle Level of Service)	5	4	No	• Data collection for a large number of parameters, equations, and methodologies was very tricky. • Collecting data before the construction of the complete street for San Fernando St. and Kentucky Ave. was difficult. • BLOS methodologies were not designed to analyze all types of bike lanes. So, they could not accurately reflect the improvements in bike safety, especially in Franklin Blvd. and Kentucky Ave. case studies. • Consider other types of BLOS calculations in future.	NR
	Level of Service (Pedestrian level of Service)	5	4	No	• Data collection for a large number of parameters, equations, and methodologies was very tricky. • Collecting data before the construction of the complete street for San Fernando St. was very difficult. • Consider other types of PLOS calculations in future.	NR
	Level of Service (Urban level of Service)	5	4	No	• Data collection for a large number of parameters, equations, and methodologies was very tricky. • Collecting data before the construction of the complete street for San Fernando St. was difficult. • Collecting data for after the construction of the Franklin Blvd. complete street was not doable.	NR
	Level of Service (Transit level of Service)	5	4	No	• Data collection for a large number of parameters, equations, and methodologies was very tricky. • Collecting data before the construction of the complete street for San Fernando St. was not doable and for Kentucky Ave. was difficult. • Collecting data for after the construction of the Franklin Blvd. complete street was difficult.	NR
	Level of Service (Bicycle Level of Stress)	1	1	No	• No problems for this indicator	R

Category	Performance Measure	Data Difficulty (1-5)	Methodology / Calculation Difficulty (1-5)	Analysis or Interpretation Issue (Yes or No)	Comments	Recommended (R) or Not Recommended (NR)
	Crashes	3	3	No	• No problems for this indicator	R
	Physical Activity and Health	5	5	No	• Collecting data considering only the complete street project was not doable.	NR
	Pedestrian Miles Traveled (PMT)	4	3	Yes/ Interpretation	• Collecting data considering only the complete street project was difficult. • There is a debate regarding how PMT should be interpreted because high PMT can imply greater use of active transportation or sparse density of destinations. • The recommendation is to keep PMT and add pedestrian trip numbers.	R
	Bicycle Miles Traveled (BMT)	4	3	Yes/ Interpretation	• Collecting data considering only the complete street project was difficult. • There is a debate regarding how BMT should be interpreted because high BMT can imply greater use of active transportation or sparse density of destinations. • The recommendation is to keep BMT and add bicycle trip numbers.	R
Livability	Green Land Consumption	5	5	No	• Collecting data considering only the complete street project was not doable.	NR
	Street Trees	1	1	No	• No problems for this indicator • Indicator should be improved by considering environmental LCA indicator effects of trees, and additional social indicators such as human thermal comfort.	R

[1: Very easy 2: Easy 3: Moderate 4: Difficult 5: Very difficult]

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Data Summary

Products of Research

The main challenges in the SLCA part of this study are data collection and the inherent context-specific and qualitative nature of social aspects of each complete street project. The evaluations of performance measures have been interpreted and discussed for each case study separately. All the performance measures were quantified for the three case studies using project-specific data. All the data, assumptions, modeling approaches, and performance measures descriptions and methodologies are explained and available in this report and the archived and published dataset document.

Data Format and Content

The data in the published dataset document is presented in Tabular form in spreadsheets. Data for SLCA for each case study, San Fernando St., Franklin Blvd., and Kentucky Ave., are organized in their relevant zipped directory.

"ELCA of complete street case studies.xlsx" (excel file) contains data that was used for performing LCA for all three case studies.

Data files can be easily accessed using Microsoft Excel. The files can also be opened using other spreadsheet software that are compatible with Microsoft Excel formats.

Data Access and Sharing

There are no restrictions for data, except for the raw results of the surveys of school principals, which are confidential per the IRB requirements of the survey.

Reuse and Redistribution

The data can be freely accessed as long as users cite the data and this report. Data citation is:

> Ostovar, Maryam; Butt, Ali Azhar; Harvey, John; Ramalingam, Zachary (2022), Socio-Economic and Environmental Life Cycle Assessment of Complete Streets: Data, Dryad, Dataset, https://doi.org/10.25338/B85K99.

Appendix A: Accessibility Assumptions and Calculations

Average walking speed:

- The average speed of Walking is 1.88 miles per hour (Yang and Diez-Roux, 2012).
- 0.84 m/s (1.88 mi/h). [Or 0.63mile in 20 minutes]
- Considering delay based on “Pedestrian and Bicyclist Delay” performance measure, the final cycling area is calculated:
- 1.88 (mi/h) * (20min-10min)/60min = 0.32 mile for children
- 3 (mi/h) * (20min-10min)/60min = 0.5 mile for average adults

Average cycling speed:

- The beginner’s speed is 10mph. So, 8 mph is assumed for children. [Or 2.67mile in 20 minutes] (Yang and Diez-Roux, 2012)
- Considering delay based on “Pedestrian and Bicyclist Delay” performance measure, the final walking area is calculated:
- 8 (mi/h) * (20min-10min)/60min = 1.33 mile for beginners
- 12 (mi/h) * (20min-10min)/60min = 2 mile for average adults

Average transit speed:

- The average speed of rail transit is 21.5 miles per hour, while the average speed of bus transit is 14.1 mph. (O’Toole 2018, Hertz 2015)
- The average public bus speed drops from 13.6 mph to 12.7 mph.
- 14 mph is assumed for the average transit speed.
- 14 (mi/h) * (20min-10min)/60min = 2.3 mile for average adults
- 20 (mi/h) * (15min-10min)/60min = 1.67 mile for average adults

Single Mode Buffers

- Walking
  - Walking Speed = 3 mph
  - Optimal trip time = 20 minutes
  - Delay: 10 minutes
  - Buffer: $\boldsymbol{3\frac{miles}{hour} * (20 - 10)mintes = 0.5\ miles}$
- Biking
  - Biking Speed = 12 mph
  - Optimal trip time = 20 minutes
  - Delay: 10 minutes
  - Buffer: $\boldsymbol{12\frac{miles}{hour} * (20 - 10)mintes = 2\ miles}$

Multi-Modal Buffers

Buffers for each mode

- Walking and Bus
  - 2 miles in 20 minutes including 10-min bus + 10-min walking
  - A pedestrian crosses the road twice, considering a 50-sec delay, which is negligible.
  - **2-mile buffer**
  - Reference Google Maps: https://www.google.com/maps/dir/37.3418199,-121.8980419/E+San+Fernando+St,+San+Jose,+CA/@37.3396405,-121.9016691,14.27z/data=!4m9!4m8!1m0!1m5!1m1!1s0x808fccc248dc86eb:0xee750dc4f51b498b!2m2!1d-121.8705735!2d37.3427555!3e3
- Walking and Train
  - It takes 4 minutes to get from Diridon Station to College Park Station
  - That leaves 16 minutes for walking including 10-min of delay (assumption+ 6-min of pure walking time
  - At 3-mph walking speed, the walking distance is 0.3 miles.
  - The train travels 1.17 miles in 4-min (measure tool in google maps)
  - 1.17+0.3 = 1.47 miles
  - **1.5-mile buffer**
- Walking and Light Rail
  - It takes 15-min to get light rail from Santa Clara Station to Metro/Airport Station, with an additional 4-min of walking +1-min of delay in walking.
  - Total distance 3.19 miles
  - **3.2-mile buffer**
  - Reference Google Maps: https://www.google.com/maps/dir/San+Antonio+Station,+San+Jose,+CA+95113/37.368398,-121.9180117/@37.3342194,-121.8922237,1023m/data=!3m1!1e3!4m9!4m8!1m5!1m1!1s0x808fccbb03bde79b:0x1b10c80522fa96ac!2m2!1d-121.8875933!2d37.3331342!1m0!3e3
- Biking and Bus
  - 10 min of transit, then 10 minutes of biking
    - 10 min transit covers 1.92 miles
  - 6 minutes of biking plus 3 minutes of delay (25 sec delay/intersection, 7 intersections), comes out to 1.1 miles
  - 1.92+1.1= 3.02 miles, rounding up to **3-mile buffer**
  - Reference Google Maps: https://www.google.com/maps/dir/37.3418827,-121.8935456/37.3406408,-121.870062/@37.3404787,-121.8915132,15.08z/data=!4m2!4m1!3e3
  - (https://www.google.com/maps/dir/37.3418568,-121.8935896/37.3548708,-121.900247/@37.3500039,-121.8990292,15.81z/data=!4m2!4m1!3e1)

- Biking and Train
  - It takes 4 minutes to get from Diridon Station to College Park Station
  - That leaves 16 minutes for biking including 13 minutes of pure biking and 3 minutes of delay
    - Biking covers 2.1 miles.
  - (https://www.google.com/maps/dir/37.3427145,-121.9156179/37.3582384,-121.9323095/@37.3565274,-121.9335545,16.33z/data=!4m2!4m1!3e1)
    - 2.1+1.17 = 3.27 miles, rounding up to **3.3-mile buffer**

- Biking and Light Rail
  - Reference Google Maps: https://www.google.com/maps/dir/Gish+Station+(North),+San+Jose,+CA+95112/37.3714096,-121.9167446/@37.3712791,-121.9167407,454m/data=!3m1!1e3!4m9!4m8!1m5!1m1!1s0x808fcb8f784b6673:0xc5ed97412fc703be!2m2!1d-121.9100781!2d37.3623803!1m0!3e1
  - It takes 15 minutes to get from Santa Clara Station to Gish Station, with an additional 4 minutes of walking and 1.25 minute of walking delay (3 intersections and 25 sec delay/intersection)—this comes out to 0.7 miles
  - Total distance: 0.7 miles + 3.19 miles = **3. 9-mile buffer**

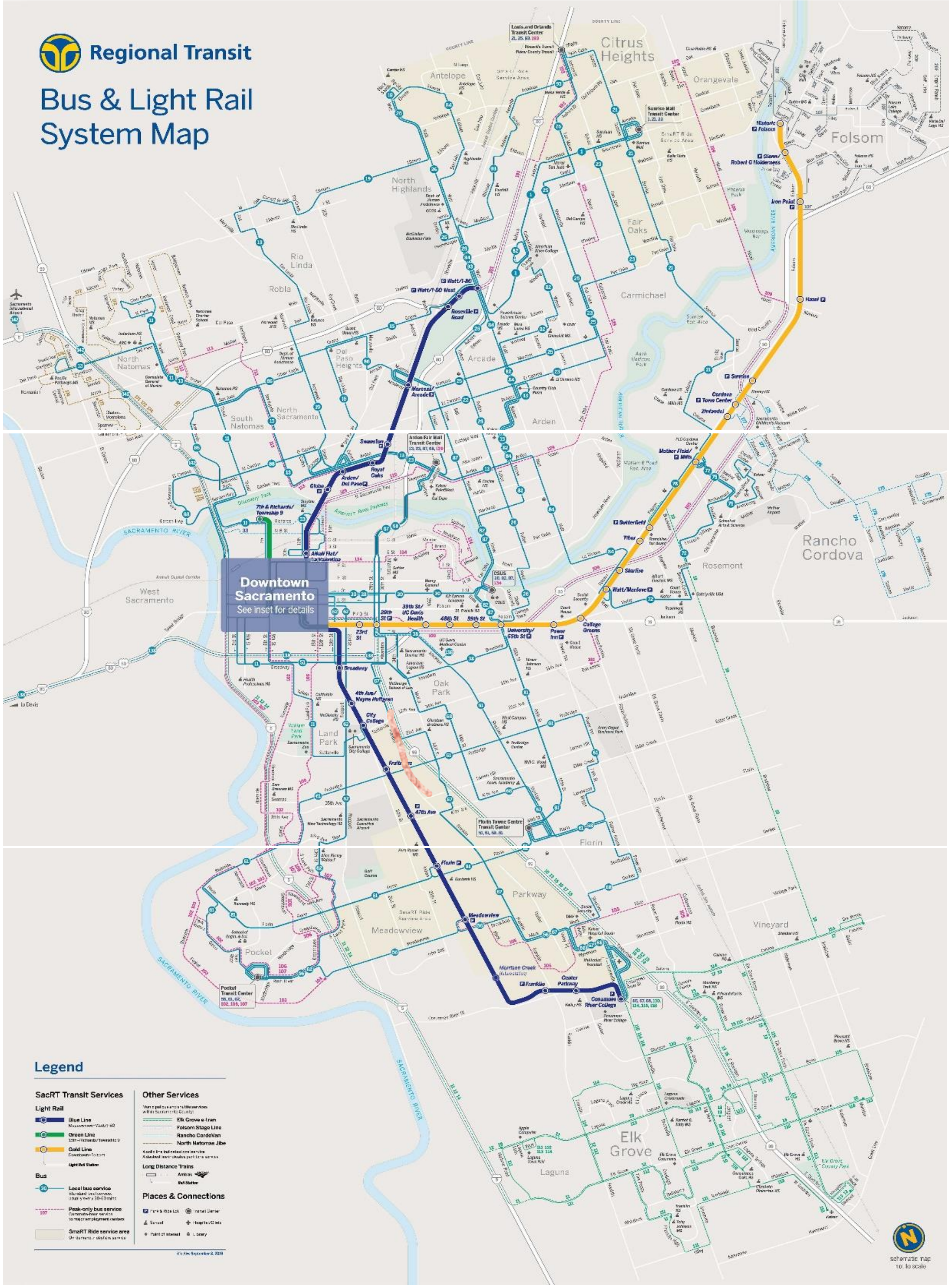


Figure 39. Sacramento County Transit Map

Appendix B: Access to Destination Calculations

Pharmacy

- According to a Walgreens publication, there are roughly 3.6 Pharmacists per store and 5.9 technicians per store. (https://www.walgreens.com/images/pdfs/state.pdf). 3.6 + 5.9 = 9.5
- Including cashiers and retail workers that work in the rest of the store: if the pharmacy is open 8am – 11pm, and there are two 8-hour shifts, and there are five workers per shift, then 9.5 + 2*(5) = roughly **20 employees per day.**
- **CVS** statistics are available from this website (https://cvshealth.com/about/facts-and-company-information). $\frac{4.5\ million\ customers}{day} \div 9900\ stores\ \frac{customers}{day} = \frac{455\ customers}{day}$.
- **Walgreens**: (https://news.walgreens.com/fact-sheets/frequently-asked-questions.htm)
- $\frac{8\ million\ customers}{day} \div 9277 stores\ \frac{customers}{day} = \frac{862\ customers}{day}$
- **Rite Aid:** https://www.riteaid.com/about-us/our-story, https://www.riteaid.com/corporate/news/-/pressreleases/news-room/2020/rite-aid-to-outline-corporate-strategy-and-growth-plan-at-analyst-day
- $\frac{1.6\ million\ customers}{day} \div 2464\ stores\ \frac{customers}{day} = \frac{650\ customers}{day}$
- The average daily customer of these three popular pharmacies is **635 customers per day.**

Coffee Shop

If the store is open from 6 am to 10 pm, the total hours would be 16 hrs. Two 8 hr shifts and three people per shift make it six employees. Add 1 for the manager, and there are **seven employees** going to work every day.

This logic took inspiration from https://www.quora.com/How-many-employees-do-I-need-for-my-coffee-shop

Starbucks has 500 customers/day (https://www.businessinsider.com/how-many-customers-starbucks-will-have-2013-10). A smaller place might have 200 (https://www.entrepreneur.com/article/334463). The average of these two is **350 customers/day**.

Restaurant

"Seated but casual dining: Customers expect more in the way of service if they are not helping themselves, and more staff per customer are needed to make sure that you keep up with the logistics of orders and clearing. One server for 5 – 6 tables per shift and four back of house staff per 50 tables is a balance that can work quite well."

Assuming there are 2 shifts per day and 30 tables, (4 back house staff + 5 servers) * 2 = **18 employees** https://www.nestleprofessional.com/news/how-many-people-do-you-need-run-your-restaurant#:~:text=One%20server%20for%20every%203,chef%20depending%20on%20your%20establishment.

Customers: According to a blog post, causal restaurants have **230 customers/day**.

(https://blog.projectionhub.com/4-financial-projection-models-for-the-4-restaurant-styles/#:~:text=Using%20an%20estimate%20of%2030,used%20in%20my%20projections%20too.)

Banks

Assume **seven employees** per branch for credit unions and 6 for banks.

https://thefinancialbrand.com/55305/banking-branch-remodel-build-transformation-trends/#:~:text=For%20new%20branches%20added%2C%20the,staffed%20by%20only%20four%20employees.

Assumptions: So 6.5% do not have a bank account. Most people visit the bank six times a year. Downtown SJ has a population of 87,113.

So $87{,}113\ people * 0.935 * 6\ \frac{visits}{person-year} = 488{,}703\ bank\ \frac{visits}{year}\ in\ downtown\ SJ.$

SJ has 37 banks. So $\frac{488{,}703\ bank\ visits}{year} \div 37\ banks \div (312\ \frac{days\ open}{year}) = \frac{42\ bank\ visits}{bank-day}$

(https://apnews.com/8b2b93d4e9474c418853e0f20e79aaa8#:~:text=In%202017%20approximately%206.5%20percent,adults%20without%20a%20bank%20account.).

https://thefinancialbrand.com/66228/bank-credit-union-branch-traffic/#:~:text=Currently%2C%20consumers%20are%20averaging%20around,two%20visits%20annually%20by%202022.

https://www.areavibes.com/san+jose-ca/downtown/demographics/

Gas Station

There are two to three employees per shift on average. If the gas station is open 24hrs/day, and there are three shifts, then 2 * 3 = **6 employees**

Shell serves 30M customers every day and has 44,000 gas stations; that works out to **682 customers/day.** (https://www.shell.com/business-customers/shell-retail-licensing/about-shell-retail.html#:~:text=Shell%20Retail%20is%20the%20world's,in%20more%20than%2075%20countries.)

Grocery store

According to EnergyStar, “The average number of employees is 0.92 per 1000 square feet (92.8 square meters) for small supermarkets and 1.10 per 1000 square feet (92.8 square meters) for large supermarkets.”

The Whole Foods in San Jose has a GSF of roughly 30,000 square feet:

$30{,}000\ ft^2 * \frac{1.1\ employees}{1000\ ft^2} =$ **33 employees**

https://www.energystar.gov/ia/business/tools_resources/target_finder/help/Space_Use_Information__Supermarket_Grocery_Store.htm#:~:text=The%20average%20number%20of%20employees%20are%200.92%20per%201000%20square,square%20meters)%20for%20large%20supermarkets.

According to research from some websites, there are 38,000 grocery stores in the US, and there are close to 32M customers per day. This comes out to **853 customers/day**.

https://spendmenot.com/grocery-shopping-statistics/#:~:text=Grocery%20stores%20in%20the%20US,million%20from%20Friday%20to%20Sunday.

Hospital

There were no hospitals within a 0.5-mile radius or a 2-mile radius of San Fernando Street, so I did not calculate this metric.

https://www.quora.com/How-many-employees-does-a-250-bed-hospital-have-on-average#:~:text=The%20answer%20to%20the%20question,needs%20to%20provide%20adequate%20services.

Post Office

According to a paper published by the Post Office, there were 496,934 employees in 2019 (https://about.usps.com/who-we-are/postal-history/employees-since-1926.pdf).

There are 31,322 Post Offices in the US (https://facts.usps.com/size-and-scope/#:~:text=There%20are%2031%2C322%20Postal%20Service,Offices%20in%20the%20United%20States.)

Therefore there is an average of $\frac{496{,}934\ employees}{31{,}322\ stores} = \boldsymbol{16\ employees/store}$

USPS statistics are available on their website. 811.8M customer visits in 2019 and 31,322 post offices work out to **71 customer visits/day**. (https://facts.usps.com/retail/#:~:text=There%20are%207.1%20million%20daily%20visits%20to%20usps.com.&text=In%202019%2C%20usps.com%20recorded,most%20frequently%20visited%20government%20sites.&text=In%202019%2C%20stamp%20and%20retail,Office%20%2D%2D%20totaled%20%24301%20million.)

Library

There are 9,075 public libraries in the US (https://libguides.ala.org/numberoflibraries). There is 136,851 paid staff in public libraries in the US. (http://www.ala.org/tools/libfactsheets/alalibraryfactsheet02).

$136{,}851\ staff/9{,}075\ libraries\ =\ 15\ employees/library$

In the fiscal year 2018/2019, the San Jose Public Library had 6,226,561 visitors. (https://www.sjpl.org/facts) With 25 branches, that comes out to 682 customers/day.

Police Station

According to the San Jose Police Department website, they have 1400 employees. All of the SJPD offices are located within 2 miles of San Fernando Street. According to an uncited Wikipedia page, there are 959 officers and 370 staff. Most officers' shifts are staggered, so the entire police force is not active at the same time. If two-thirds are deployed every day, and one-third of staff do not work at the police station, then (1/3)*370 + (2/3)*(959) = **762 employees**

According to an article from the Mercury News, (https://www.mercurynews.com/2020/06/24/sjsu-students-faculty-petition-to-defund-reform-campus-police/#:~:text=The%20University%20Police%20Department%20consists,according%20to%20the%20SJSU%20website.) SJSUPD has 32 sworn officers and 45 civilian employees.

Using a similar methodology to the above, (2/3)*32 + 45 = **66 employees/day**

According to the SJPD website, there were 29,725 arrests in 2019. There are 81 arrests per day and are assumed to round up to **100 "customers"/day**.

Places of Worship

Assumptions: According to the Hartford Institute of Religion, 59% of churches have attendance between 1-99. Assuming that churches meet twice a week and that staff of 5 people go to the church office every day, $\frac{99*2+5(6)}{7} = \mathbf{32\ people/day}$ (http://hirr.hartsem.edu/research/fastfacts/fast_facts.html#sizecong)

Museum

Thirty-one employees are listed on the San Jose Museum of Art website.

44 staff are mentioned on the San Jose Children's Discovery Museum.

13 staff at the Quilts and Textiles Museum

Assumption: in San Jose, 2/3 of the museums are small, and 1/3 are big. Big museums have around 38 employees (the average of 31 and 44), and small museums have 13.

$$\frac{2}{3} * 38 + \frac{1}{3} * 13 = 30\ employees$$

The San Jose Museum of art serves more than 100,000 visitors (https://sjmusart.org/about). If they are open seven days a week, that works out to **273 visitors/day**.

Government Buildings Methodology

Two criteria are needed to determine accessibility to jobs for government offices, including the number of government buildings and a number of people working in each building. The number of government buildings is found from Google Maps or a similar mapping application. However, the number of people working in each building is usually unavailable on the internet, so it is necessary to make some estimates. One method is to find the gross square footage (GSF) of the buildings using Google Maps (using the measure tool) and then look up County or City guidelines on how much space is allocated per person. However, not all GSF is usable space for employees since space is commonly taken up by elevators, walls, and support pillars. Therefore, it is necessary to determine the usable square footage (USF), as the assignable square footage (ASF). Dividing the ASF by the average space per person estimates the number of employees in that building. Some helpful references include:

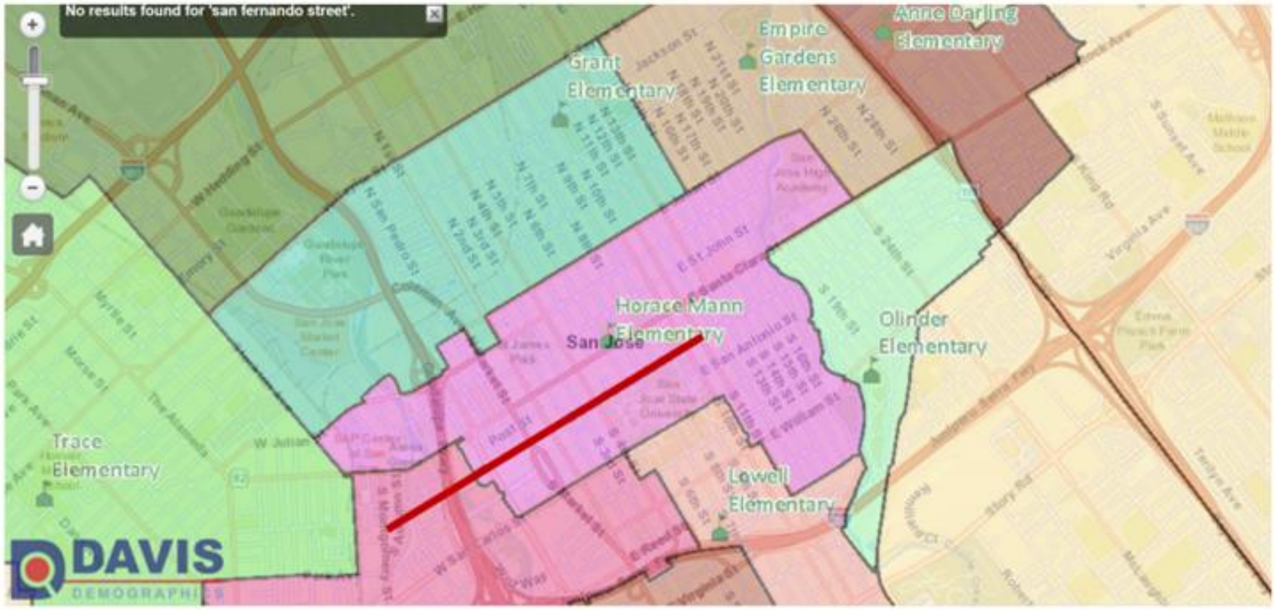
- the Government Accountability Office published guidelines for space utilization (U.S. government accountability Office, 2018),
- Virginia Tech published a policy paper that describes how much of the Gross Square Footage (GSF) is Assignable Square Footage (ASF). The ratio of ASF/GSF for office buildings with partitioned offices should be roughly 70% (Virginia Tech, 2020).
- California State University: According to a policy from the CalState university system, “Depending on the type of facility, the ratio [of ASF/GSF] should be no less than 60%.” (California State University, 2019),
- Austin Tenant Advisors (access at June 2020 at https://www.austintenantadvisors.com/blog/what-is-the-average-square-footage-of-office-space-per-person/)

  It would be reasonable to use a ratio of ASF/GSF within the range of 60-70%. For the calculations in this report, an average ratio of 65% was used to estimate the number of employees.

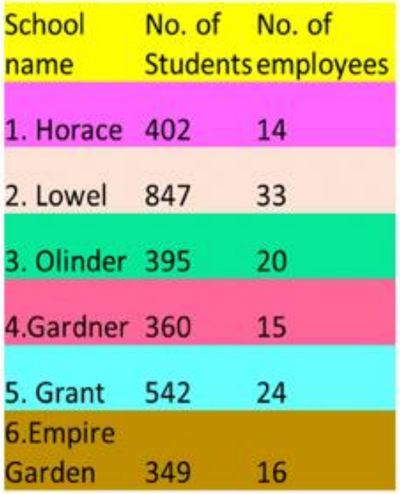
Some useful terms in this regard include:

- GSF: Gross Square Footage
- ASF: Assignable Square Footage
- USF: Usable Square Feet (USF) per person or density
- No. of employees: ASF/USF

Appendix C: Access to School Complementary Information



No results found for 'san fernando street'.



School name	No. of Students	No. of employees
1. Horace	402	14
2. Lowel	847	33
3. Olinder	395	20
4.Gardner	360	15
5. Grant	542	24
6.Empire Garden	349	16

Figure 40. Access to School (considering school district boundary)- San Fernando Case Study

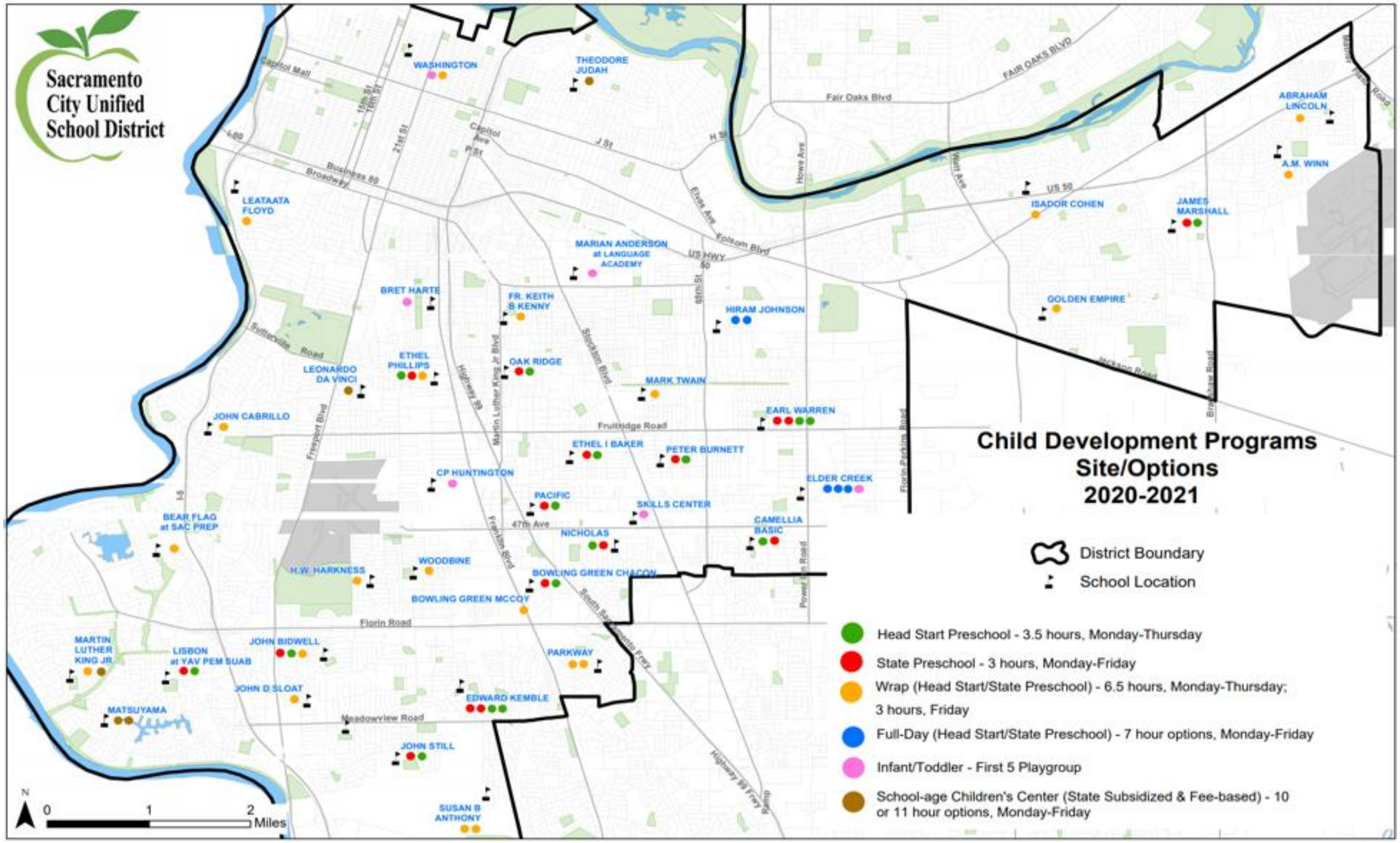


Figure 41. Sacramento City Unified School District (including 81 schools)

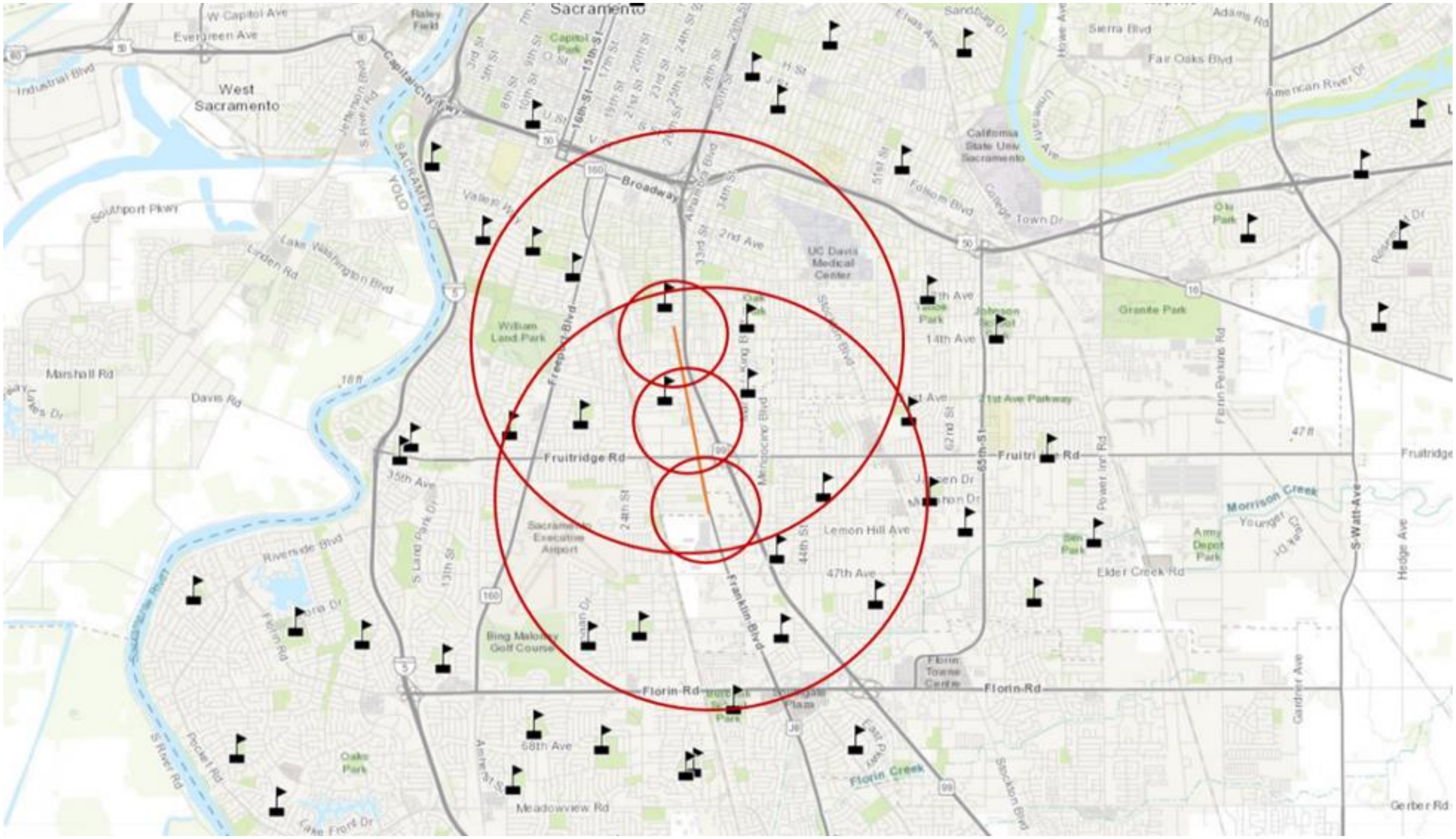


Figure 42. Sacramento City School maps combined with the 0.5-mile walking and 2-mile cycling Circular buffer *(https://saccityusd.maps.arcgis.com/apps/webappviewer/index.html?id=65299203ccef4df4969dc9169f61a424)*

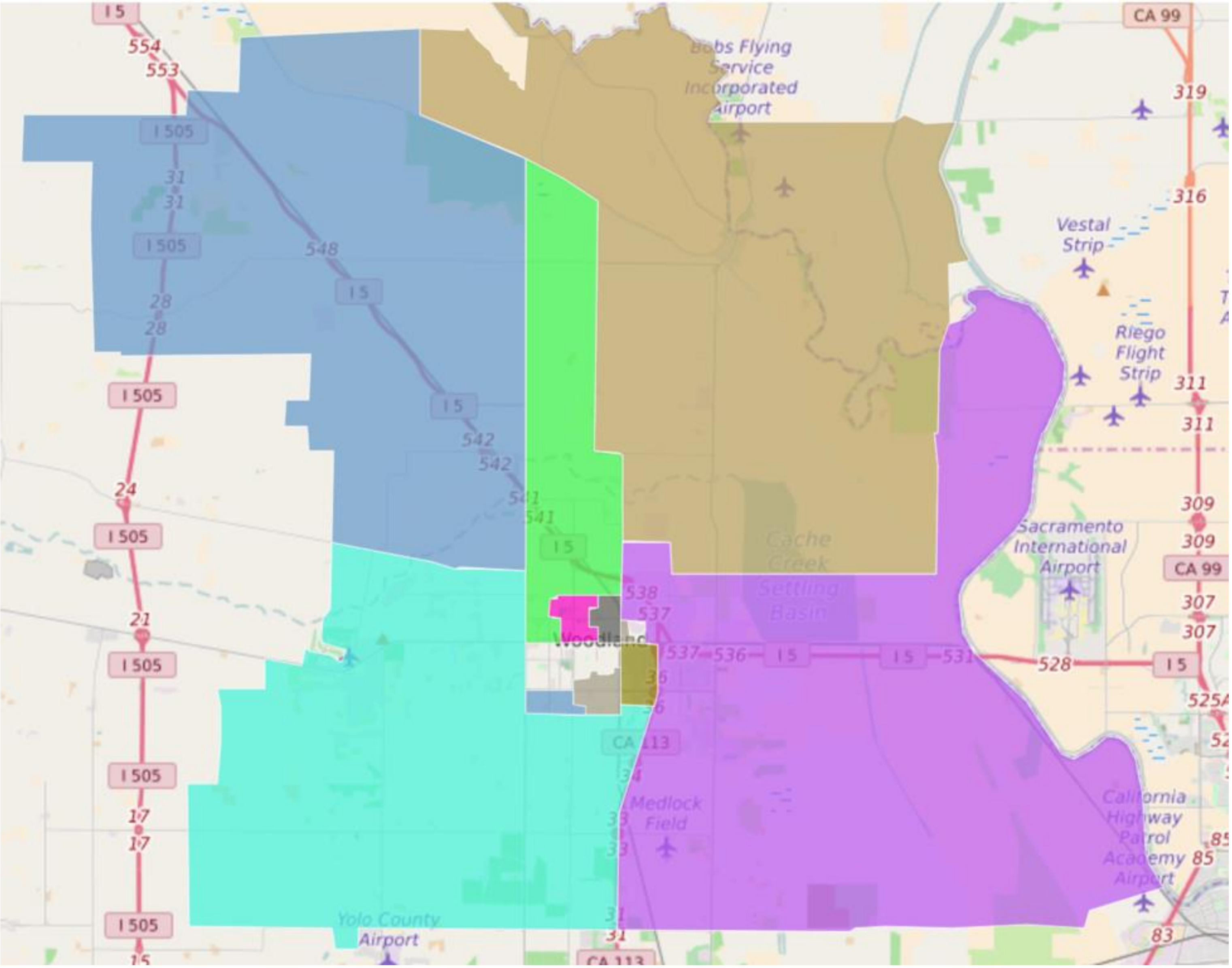


Figure 43. Map of Woodland Joint Unified School District

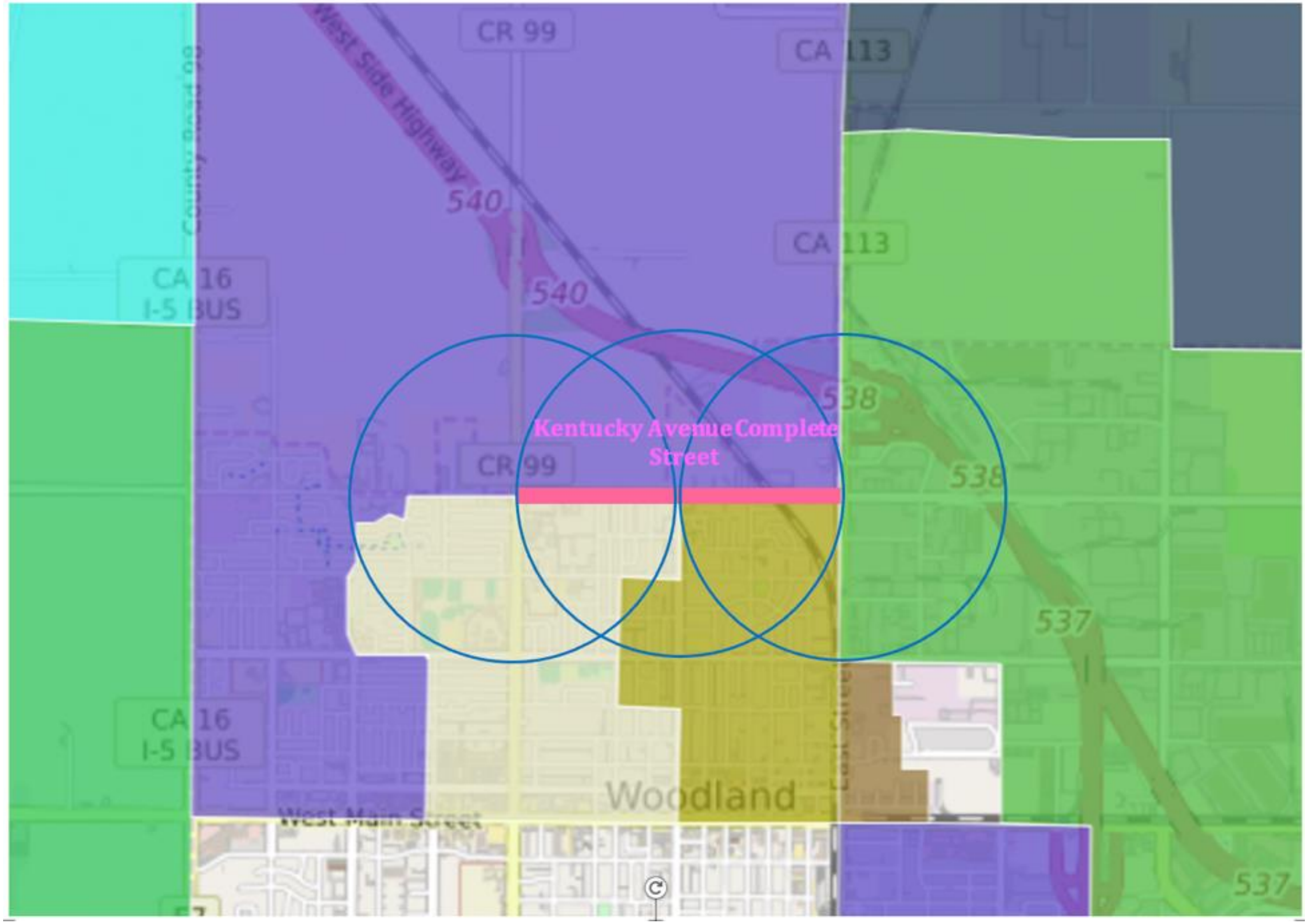


Figure 44. City of Woodland school maps combined with the 0.5-mile walking and 2-mile cycling Circular buffer

Example of Survey for School Principals

University of California, Davis

Letter of Information

Title of study: Life Cycle Assessment of Complete Streets: Case Studies

Investigator: Professor John Harvey

Survey identifier:

Introduction and Purpose

You are being invited to join a research study. If you agree to participate in this research, you will be asked to provide answers to the best of your knowledge about travel by students to your school, and students' and parents' perceptions. Your participation in this research should take no more than one hour of your time.

You understand that the results of this study will be used to improve the quantification of benefits to students from the conversion of streets into complete streets. Any responses you provide will be anonymized, so no one other than the research team (consisting of the principal investigator [PI], co-PI, and research assistant) will know which is yours. Your school's name will also be anonymous; however some other data such as distances of the school from transit stations and streets will be included and published in the report. The research team will not be collecting or requesting any personal data of you (principals), students or parents. You may fill in the survey and email it to the research team, or we will fill it out with you through a phone/web meeting.

Participation in research is completely voluntary. You are free to decline to take part in the project. You can decline to answer any questions and you can stop taking part in the project at any time. Whether or not you choose to participate, or answer any question, or stop participating in the project, there will be no penalty to you or loss of benefits to which you are otherwise entitled.

Questions

If you have any questions about this research, please feel free to contact the investigators:

- PI (*5102068349 or jtharvey@ucdavis.edu*)
- Co-PI (*aabutt@ucdavis.edu*)

Accessibility to School Survey
Spring 2021
-Questionnaire for the X Complete Street Project-

This *Questionnaire* is designed to aid our understanding about how children get to school and parent perceptions of safety and convenience including transit services and active transportation now available as a result of the San Fernando complete streets project located in the City of X. The research team is interested in:

- Estimates of mode choice between student's homes and schools, and
- Understanding the effects of complete streets on student travel to and from school.

This research is being performed with a grant from the National Center for Sustainable Transportation at UC Davis. The research being conducted investigates the social and economic impacts of complete streets improvements in transit corridors near public schools. The study of transit near schools requires our focus on public schools near the project site. We do not want to interview students and parents, but instead assess their perceptions and choices by surveying the principals of the schools. There are X schools located near the X complete street project. The research team will be requesting the school principals to fill in the survey. If they prefer to provide their feedback on the phone or web meeting, no more than one-hour interviews will be conducted. This same survey questionnaire will be used as the interview script.

The questions mainly focus on how the complete street project affects students' commutes in terms of safety and time. No personal information about students or parents is being requested. We will keep the identities of the principals interviewed confidentially[7].

The final report will include publicly available data (such as distances to streets and transit stations, number of students, other information about student population) and analyzed results without stating the school name or principal's name. Importantly, school principals may decline to take part in this survey and can choose to stop participating at any time, for any reason, when being interviewed.

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[7] The research team affirms that they, as the only authorized people, will have access to the identifiers, which will be stored on computers, electronic notebooks, mobile devices, and/or data-storage devices encrypted and password-protected, and will be kept in a locked area (if maintained in paper format) with access limited only to research team who require access to conduct the study. Identifiers will be removed from the identifiable private information and after the data are de-identified, they could be used for future research studies or distributed to another researcher. The survey information collected as part of the research, and even if identifiers are removed, they will not be used or distributed for future research studies.

Questionnaire for Principals of Elementary Schools

NOTE: All questions are with regard to travel before and after completion of the X complete street project and before Covid closures of schools in March 2020.

1. Based upon what you know about your students, what percentage of your students reside outside the district attendance boundaries for your school?

2. Based upon what you know about your students and their parents, do parents use the proposed complete X street when dropping off/ picking up students to/from school?

3. Based upon your estimation, do students use X the proposed complete street when commuting to or from school?

4. What do you think can be done to improve accessibility and safety for students commuting to school? Does the X complete street conversion help?

5. Based upon what you know about your students, what percentage of students take the following modes of transportation to/from school based on the season, <u>(after building the complete street conversion and before the Covid closure)</u>?

Season	**Walk**	**Bike**	**Bus/Train**	**Car**	**Combination trip**	**Other**
Fall						
Winter						
Spring						

6. Based upon what you know about your students, what percentage of students took the following modes of transportation to/from school based on the season <u>(before building a complete street)</u>?

Season	**Walk**	**Bike**	**Bus/Train**	**Car**	**Combination trip**	**Other**
Fall						
Winter						
Spring						

7. Based upon the age and grade of your students, can you estimate the time it takes your students to commute to school?

Time	**Walk (Kinder-garten)**	**Walk (1st to 5th grade)**	**Bike (Kinder-garten)**	**Bike (1st to 5th grade)**	**Bus/ Train (Kinder-garten)**	**Bus/Train (1st to 5th grade)**	**Car (Kinder-garten)**	**Car (1st to 5th grade)**	**Combination trip (Kinder-garten)**	**Combination trip (1st to 5th grade)**	**Other**
0-10 minutes											
11-20 minutes											
21-30 minutes											
31-40 minutes											

8. Please provide an estimate of what percentages of students walk or bike without adult supervision (on their own or with other children), by their grade in school:

Grade	**Kindergarten**	**1st**	**2nd**	**3rd**	**4th**	**5th**
Percentage Biking						
Percentage Walking						

9. Which street is the main route for students to take to school based on your estimation?

Mode	**Walk**	**Bike**	**Train/Bus**	**Car**	**Other**
Main route(s)					

10. Do you think parents perceive that the X complete street project has made it safer?

11. Based upon your estimation, do your students feel safe and comfortable when walking/ biking or using transit?

12. Does your school have enough bike parking for the students? If yes, what kind of security for bike parking do you have?

13. Based on your perception, how safe do you think it is for students to bike/walk or use transit or combined bike or walk and transit to school? If not, please explain why (eg. no bike lanes, heavy traffic, street crime, etc.)

14. Do you think parents feel comfortable with their children:
    a. biking/walking or using transit to school alone?
    b. biking/walking or using transit to school with at least one adult?
    c. traveling to school with other children?

15. From your observations and what you know about your students, what additional streets, corridors or intersections used by students to travel to school need improvements or repairs to make them safer and more comfortable walking, biking, and using transit?

16. Based on what you know about the school district, are there any recent changes in school district activity that may influence where a student attends school? (e.g., students are going to different schools and the students may no longer be able to walk or bike to school; or students will be passing through the complete streets project to get to their new school)?

Questionnaire for Principals of Middle Schools

NOTE: All questions are with regard to travel before and after completion of the X complete street project and before Covid closures of schools in March 2020.

1. Based upon what you know about your students, what percentage of your students reside outside the district attendance boundaries for your school?

2. Based upon what you know about your students and their parents, do parents use Xcomplete street when dropping off/ picking up students to/from school?

3. Based upon your estimation, do students use X complete street when commuting to or from school?

4. What do you think can be done to improve accessibility and safety for students commuting to school? Does the Xcomplete street conversion help?

5. Based upon what you know about your students, what percentage of students take the following modes of transportation to/from school based on the season, (after building the complete street conversion and before the Covid closure)?

Season	Walk	Bike	Bus/Train	Car	Combination trip	Other
Fall						
Winter						
Spring						

6. Based upon what you know about your students, what percentage of students took the following modes of transportation to/from school based on the season (before building a complete street)?

Season	Walk	Bike	Bus/Train	Car	Combination trip	Other
Fall						
Winter						
Spring						

7. Based upon the age and grade of your students, can you estimate the time it takes your students to commute to school?

Time	**Walk (6th to 8th grade)**	**Bike (6th to 8th grade)**	**Bus/Train (6th to 8th grade)**	**Car (6th to 8th grade)**	**Combination trip (6th to 8th grade)**	**Other**
0-10 minutes						
10-20 minutes						
20-30 minutes						
30-40 minutes						

8. Please provide an estimate of what percentages of students bike or walk to school without adult supervision (on their own), by their grade school:

Grade	**6th**	**7th**	**8th**
Percentage Biking			
Percentage Walking			

9. Which street is the main route for students to take to school based on your estimation?

Mode	**Walk**	**Bike**	**Train/Bus**	**Car**	**Other**
Main route(s)					

10. Do you think parents perceive that the complete street project has made it safer?

11. Based upon your estimation, do your students feel safe and comfortable when walking/ biking or using transit?

12. Does your school have enough bike parking for the students? If yes, what kind of security for bike parking do you have?

13. Based on your perception, how safe do you think it is for students to bike/walk or use transit or combined bike or walk and transit to school? If not, please explain why (eg. no bike lanes, heavy traffic, street crime, etc.)

14. Do you think parents feel comfortable with their children:
    a. biking/walking or using transit to school alone?
    b. biking/walking or using transit to school with at least one adult?
    c. traveling to school with other children?

15. From your observations and what you know about your students, what additional streets, corridors or intersections used by students to travel to school need improvements or repairs to make them safer and more comfortable walking, biking, and using transit?

16. Based on what you know about the school district, are there any recent changes in school district activity that may influence where a student attends school? (e.g., students are going to different schools and the students may no longer be able to walk or bike to school; or students will be passing through the complete streets project to get to their new school)?

Questionnaire for Principals of High Schools

NOTE: All questions are with regard to travel before and after completion of the X complete street project and before Covid closures of schools in March 2020.

1. Based upon what you know about your students, what percentage of your students reside outside the district attendance boundaries for your school?

2. Based upon what you know about your students and their parents, do parents use complete street when dropping off/ picking up students to/from school?

3. Based upon your estimation, do students use Xcomplete street when commuting to or from school?

4. What do you think can be done to improve accessibility and safety for students commuting to school? Does the complete street conversion help?

5. Based upon what you know about your students, what percentage of students take the following modes of transportation to/from school based on the season, <u>(after building the complete street conversion and before the Covid closure)</u>?

Season	**Walk**	**Bike**	**Bus/Train**	**Car**	**Combination trip**	**Other**
Fall						
Winter						
Spring						

6. Based upon what you know about your students, what percentage of students take the following modes of transportation to/from school based on the season <u>(before building a complete street)</u>?

Season	**Walk**	**Bike**	**Bus/Train**	**Car**	**Combination trip**	**Other**
Fall						
Winter						
Spring						

7. How long does it take students of different ages to commute to school for each mode based on your estimation?

Time	**Walk (9th to 10th grade)**	**Walk (11th to 12th grade)**	**Bike (9th to 10th grade)**	**Bike (11th to 12th grade)**	**Bus/Train (9th to 10th grade)**	**Bus/Train (11th to 12th grade)**	**Car (9th to 10th grade)**	**Car (11th to 12th grade)**	**Combination trip (9th to 10th grade)**	**Combination trip (11th to 12th grade)**	**Other**
0-10 minutes											
10-20 minutes											
20-30 minutes											
30-40 minutes											

8. Please provide an estimate of what percentages of students bike or walk to school without adult supervision (by their own), by class:

Grade	9th	10th	11th	12th
Biking Percentage				
Walking Percentage				

9. Which street is the main route for students to take to school based on your estimation?

Mode	**Walk**	**Bike**	**Train/Bus**	**Car**	**Other**
Main route(s)					

10. Do you think parents perceive that the X complete street project has made it safer?

11. Based upon your estimation, do your students feel safe and comfortable when walking/ biking or using transit?

12. Does your school have enough bike parking for the students? If yes, what kind of security for bike parking do you have?

13. Based on your perception, how safe do you think it is for students to bike/walk or use transit or combined bike or walk and transit to school? If not, please explain why (eg. no bike lanes, heavy traffic, street crime, etc.)

14. Do you think parents feel comfortable with their children:
    a. biking/walking or using transit to school alone?
    b. biking/walking or using transit to school with at least one adult?
    c. traveling to school with other children?

15. From your observations and what you know about your students, what additional streets, corridors or intersections used by students to travel to school need improvements or repairs to make them safer and more comfortable walking, biking, and using transit?

16. Based on what you know about the school district, are there any recent changes in school district activity that may influence where a student attends school? (e.g., students are going to different schools and the students may no longer be able to walk or bike to school; or students will be passing through the complete streets project to get to their new school)?

17. Do you have a magnet program for students who live outside your school's boundaries?

Appendix D: Level of Traffic Stress Complementary Tables

Tables used in the calculation of LTS for the San Fernando Case Study derived from Montgomery LTS tables (Montgomery County Bicycle Master Plan, 2018)

Table 107. Intersection LTS used for finding the LTS for Before and After Building the Complete Street

	# of Lanes of Street Being Crossed					
Posted Speed Limit on Street Being Crossed	No Median Refuge			Median Refuge (≥6 ft wide)		
	2 to 3	4 to 5	6+	2 to 3	4 to 5	6+
≤25	1	2	4	1	1	2
30	1	2	4	1	2	3
35	2	3	4	2	3	4
≥40	3	4	4	3	4	4

The width of the bike lane and the parking, before building the complete street is 13.4 feet, which is less than 14 ft. Therefore, the LTS for before building the Complete Street is 2.5 because

Table 108. Bike Lanes used for finding the LTS for After Building the Complete Street

Street Segments: Revised Level of Traffic Stress
Bikeway: Bike Lanes

Posted Speed Limit (mph)	# of Through Lanes	Bike Lanes						
		No Parking			Parking			
		Infrequently Obstructed		Frequently Obstructed	Infrequently Obstructed / Low Parking Turnover			Frequently Obstructed / High Parking Turnover
		Bike Lane ≤ 5.5 ft	Bike Lane ≥ 6.0 ft		Bike Lane + Parking	Bike Lane + Parking = 14.0 – 14.5 ft	Bike Lane + Parking = 15.0 ft	
≤25	2-3	2	1	2.5	2.5 (2a)	2	1	2.5
	4-5	2.5 (2b)	2.5 (2b)	2.5	3			
	≥6	3			3			
30	2-3	2	2	2.5	2.5	2	2	2.5
	4-5	2.5 (2b)	2.5 (2b)	2.5	3			
	≥6	3			3			
35	2-3	3			3			
	4-5							
	≥6							
40	2-3	3			n/a			
	4-5	4 (3b)						
	≥6	4						
≥45	2-3	4			n/a			
	4-5							
	≥6							

Table 109. Shared/ Separated Bike Lanes used for finding the LTS for After Building the Complete Street

Street Segments: Revised Level of Traffic Stress
Bikeway: Sidepaths, Independent Right-of-Way and Separated Bike Lanes

		Shared Use Path			Separated Bike Lanes			
Posted Speed Limit (mph)	# of Through Lanes	Sidepath with Buffer < 5 ft (and no railing) OR Many Driveways	Sidepath with Buffer ≥ 5 ft (or railing) AND Few Driveways	Independent ROW	Flex Posts	Separated Bike Lanes with Buffer < 5 ft (and no railing) OR Many Driveways	Separated Bike Lanes with Buffer ≥ 5 ft (or railing) AND Few Driveways	Parked Cars
≤25	3-Feb	2 (1f)	1	0	1	2 (1f)	1	1
	5-Apr				2			
	≥6				2.5			
30	3-Feb	2 (1f)	1	0	2	2 (1f)	1	1
	5-Apr				2.5			
	≥6				2.5			
35	3-Feb	2 (1f)	1	0	2	2 (1f)	1	1
	5-Apr				2.5			
	≥6				2.5			
40	3-Feb	2	2 (1e)	0	2.5	2	2 (1e)	n/a
	5-Apr							
	≥6							
≥45	3-Feb	2	2 (1e)	0	2.5	2	2 (1e)	n/a
	5-Apr							
	≥6							

Tables used in the calculation of LTS for Franklin Boulevard and Kentucky Avenue Case Study (Furth, 2017)

Table 110. LTS for Segment by Bikeway Type

Segment Type	Level of Traffic Stress
Stand-alone paths	LTS = 1
Segregated paths (sidepaths, cycle tracks)	LTS = 1
Bike lanes	LTS can vary from 1 to 4; see Tables 2 and 3
Mixed traffic	LTS can vary from 1 to 4; see Table 4

Table 111. Criteria for Bike Lanes Alongside a Parking Lane

	LTS ≥ 1	**LTS ≥ 2**	**LTS ≥ 3**	**LTS ≥ 4**
Street width (thru lanes per direction)	1	2, if directions are separated by a raised median	More than 2, or 2 without a separating median	(n.a.)
Bike lane width	6 ft or more	5.5 ft or less	(n.a.)	(n.a.)
Speed limit or prevailing speed	30 mph or less	(n.a.)	35 mph	40 mph or more
Bike lane blockage	rare	(n.a.)	frequent	(n.a.)

Note: Dimensions aggregate using Weakest Link logic

Table 112. Criteria for Mixed Traffic

		Street Width	
Speed Limit or Prevailing Speed	2-3 lanes	4-5 lanes	6+ lanes
Up to 25 mph	LTS 1 [a] or 2 [a]	LTS 3	LTS 4
30 mph	LTS 2 [a] or 3 [a]	LTS 4	LTS 4
35+ mph	LTS 4	LTS 4	LTS 4

[a] Use lower value for streets without marked centerlines and with ADT ≤ 3000; use higher value otherwise.

Table 113. Criteria for Bike Lanes and Mixed Traffic on Intersection Approaches in the Presence of a Right Turn Lane

Configuration	Level of Traffic Stress
Single RT lane up to 150 ft long, starting abruptly while the bike lane continues straight; intersection angle such that turning speed is ≤ 15 mph.	LTS ≥ 2
Single RT lane longer than 150 ft, starting abruptly while the bike lane continues straight; intersection angle such that turning speed is ≤ 20 mph.	LTS ≥ 3
Single RT lane in which the bike lane shifts to the left, but the intersection angle and curb radius are such that turning speed is ≤ 15 mph.	LTS ≥ 3
Single RT lane with any other configuration; dual RT lanes; or RT lane plus option (through-right) lane.	LTS = 4

Note: “Bike lane” here means either a pocket bike lane (between the RT lane and a through lane), or a bike lane marked within the right turn lane. These criteria do not apply if a segregated bike lane is kept to the right of a right turn lane and provided a safe means of crossing.

Table 114. Criteria for Unsignalized Crossings

a. NO CROSSING ISLAND	**Width of Street Being Crossed**		
Speed Limit or Prevailing Speed	Up to 3 lanes	4 - 5 lanes	6+ lanes
Up to 25 mph	LTS 1	LTS 2	LTS 4
30 mph	LTS 1	LTS 2	LTS 4
35 mph	LTS 2	LTS 3	LTS 4
40+	LTS 3	LTS 4	LTS 4

b. WITH CROSSING ISLAND	**Width of Street Being Crossed**		
Speed Limit or Prevailing Speed	Up to 3 lanes	4 - 5 lanes	6+ lanes
Up to 25 mph	LTS 1	LTS 1	LTS 2
30 mph	LTS 1	LTS 2	LTS 3
35 mph	LTS 2	LTS 3	LTS 4
40+	LTS 3	LTS 4	LTS 4

Appendix E: Itemized Environmental LCA Impact Results

Table 115. Itemized Impacts of The Conventional Option During the Analysis Period for Materials, Transportation, and Construction Stages- San Fernando Street

Treatment (during the analysis period)	Functional Unit	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]	Service Life [yrs]	Thickness (cm)	# of Treat. App.	Width (m)	# per block	Note	Share of this item in Total GWP
HMA (overlay)	1 Block	3.33E+04	4.21E+03	2.13E+01	3.80E+05	1.21E+06	10.0	8.9	3	3.70	3	Street Top Layer	40.6%
Aggregate, Crushed	1 Block	1.77E+04	3.14E+03	6.75E+00	2.73E+05	0.00E+00	15.0	33.0	2	3.70	3	Street AB	21.6%
PCC	1 Block	1.38E+04	1.28E+03	7.57E+00	1.07E+05	0.00E+00	20.0	15.2	2	0.91	2	Curb & Gutter Surface	16.9%
Aggregate, Crushed	1 Block	1.17E+03	2.07E+02	4.45E-01	1.80E+04	0.00E+00	15.0	15.2	2	0.91	2	Curb & Gutter AB	1.4%
Planting	1 Block	1.91E+01	1.07E+01	6.56E-02	7.71E+02	0.00E+00	5.0	NA	6	1.83	2	Landscape	0.0%
PCC	1 Block	1.39E+04	1.29E+03	7.63E+00	1.08E+05	0.00E+00	20.0	9.2	2	1.52	2	Sidewalk Surface	17.0%
Aggregate, Crushed	1 Block	1.95E+03	3.45E+02	7.42E-01	3.00E+04	0.00E+00	15.0	15.2	2	1.52	2	Sidewalk AB	2.4%
Total	**1 Block**	**8.19E+04**	**1.05E+04**	**4.45E+01**	**9.17E+05**	**1.21E+06**							

Table 116. Itemized Impacts of The Complete Street Option During the Analysis Period for Materials, Transportation, and Construction Stages- San Fernando Street

CS Element	Material	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]	Service Life	# per Block	Length (m)	Width (m)	Area of the Element (m2)	% of area that is replacing conventional treatment	Total Mass/Area/Length/Count over that of the CS element in the CS tab
Coloring Lanes	Paint (area)	6.77E-03	8.33E-02	6.19E-07	1.09E-02	0.00E+00	3	2	81	2.44	197	0%	394
Shelter/ Transit station	PCC on AB	3.75E+03	3.77E+02	1.99E+00	3.17E+04	0.00E+00	15	1	15	3.00	45	100%	45
Planted Furniture Zone	Planting	1.18E+01	2.45E+00	1.50E-02	1.76E+02	0.00E+00	5	1	61	3.00	182	100%	182
Curb Type 5	PCC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	15	1		NA	NA	0%	0
Coloring Lanes	Paint (area)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3	2			0	0%	0
Raised Bicycle Buffer	HMA (overlay)	2.26E+02	2.86E+01	1.45E-01	2.59E+03	8.22E+03	10	2	81	NA	NA	0%	162
Buffered Cycle Track	HMA (overlay)	1.27E-03	1.56E-02	1.16E-07	2.05E-03	0.00E+00	3	2	81	1.52	123	100%	246
Total (for 1 Block)		**3.99E+03**	**4.08E+02**	**2.15E+00**	**3.45E+04**	**8.22E+03**							

Table 117. Itemized Impacts of The Conventional Option During the Analysis Period for Materials, Transportation, and Construction Stages- Franklin Boulevard

Treatment (during the analysis period)	Functional Unit	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]	Service Life [yrs]	Thickness (cm)	# of Treat. App.	Salvage (% of Service Life)	Width (m)	# per block	Note	Share of this item in Total GWP
HMA (overlay)	1 Block	4.27E+04	5.40E+03	2.73E+01	4.88E+05	1.55E+06	10.0	8.9	3	0%	3.70	3	Street Top Layer	40.6%
Aggregate, Crushed	1 Block	2.27E+04	4.03E+03	8.67E+00	3.50E+05	0.00E+00	15.0	33.0	2	0%	3.70	3	Street AB	21.6%
PCC	1 Block	1.78E+04	1.64E+03	9.72E+00	1.37E+05	0.00E+00	20.0	15.2	2	50%	0.91	2	Curb & Gutter Surface	16.9%
Aggregate, Crushed	1 Block	1.50E+03	2.65E+02	5.71E-01	2.31E+04	0.00E+00	15.0	15.2	2	0%	0.91	2	Curb & Gutter AB	1.4%
Planting	1 Block	2.45E+01	1.38E+01	8.41E-02	9.90E+02	0.00E+00	5.0	NA	6	0%	1.83	2	Landscape	0.0%
PCC	1 Block	1.79E+04	1.65E+03	9.79E+00	1.38E+05	0.00E+00	20.0	9.2	2	50%	1.52	2	Sidewalk Surface	17.0%
Aggregate, Crushed	1 Block	2.50E+03	4.42E+02	9.52E-01	3.85E+04	0.00E+00	15.0	15.2	2	0%	1.52	2	Sidewalk AB	2.4%
Total	**1 Block**	**1.05E+05**	**1.34E+04**	**5.71E+01**	**1.18E+06**	**1.55E+06**								

Table 118. Itemized Impacts of The Complete Street Option During the Analysis Period for Materials, Transportation, and Construction Stages- Franklin Boulevard

CS Element	Material	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]	Service Life (yrs)	# per Block	Length (m)	Width (m)	Area of the Element (m2)	% of area that is replacing conventional treatment	Total Mass/Area/ Length/ Count over that of the CS element in the CS tab
Coloring Lanes	Paint (area)	7.60E-03	9.35E-02	6.95E-07	1.23E-02	0.00E+00	3	2	104	2.13	221	0%	442
Shelter/Transit station	PCC on AB	3.75E+03	3.77E+02	1.99E+00	3.17E+04	0.00E+00	15	1	15	3.00	45	100%	45
Planted Furniture Zone	Planting	1.08E+01	2.25E+00	1.37E-02	1.62E+02	0.00E+00	5	1	84	2.00	167	100%	167
Curb Type 5	PCC	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	15	1		NA	NA	0%	0
Coloring Lanes	Paint (area)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3	2			0	0%	0
Raised Bicycle Buffer	HMA (overlay)	2.90E+02	3.67E+01	1.86E-01	3.32E+03	1.05E+04	10	2	104	NA	NA	0%	207
Buffered Cycle Track	HMA (overlay)	6.51E-04	8.01E-03	5.95E-08	1.05E-03	0.00E+00	3	2	104	0.61	63	100%	126
Total (for 1 Block)		**3.99E+03**	**4.05E+03**	**4.16E+02**	**2.19E+00**	**3.52E+04**							

Table 119. Itemized Impacts of The Conventional Option During the Analysis Period for Materials, Transportation, and Construction Stages- Kentucky Avenue

	Treatment (during the analysis period)	Functional Unit	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]	Service Life [yrs]	Thickness (cm)	# of Treat. App.	Salvage (% of Service Life)	Width (m)	# per block	Note	Share of this item in Total GWP
West Kentucky	HMA (overlay)	1 Block	8.47E+04	1.07E+04	5.43E+01	9.68E+05	3.08E+06	10.0	8.9	3	0%	3.70	3	Street Top Layer	38.0%
	Aggregate, Crushed	1 Block	3.47E+04	6.15E+03	1.32E+01	5.35E+05	0.00E+00	15.0	25.4	2	0%	3.70	3	Street AB	15.6%
	PCC	1 Block	4.63E+04	4.28E+03	2.53E+01	3.57E+05	0.00E+00	20.0	15.2	2	50%	0.91	2	Curb & Gutter Surface	20.8%
	Aggregate, Crushed	1 Block	3.90E+03	6.91E+02	1.49E+00	6.02E+04	0.00E+00	15.0	15.2	2	0%	0.91	2	Curb & Gutter AB	1.8%
	Planting	1 Block	6.39E+01	3.59E+01	2.19E-01	2.58E+03	0.00E+00	5.0	NA	6	0%	1.83	2	Landscape	0.0%
	PCC	1 Block	4.66E+04	4.31E+03	2.55E+01	3.60E+05	0.00E+00	20.0	9.2	2	50%	1.52	2	Sidewalk Surface	20.9%
	Aggregate, Crushed	1 Block	6.51E+03	1.15E+03	2.48E+00	1.00E+05	0.00E+00	15.0	15.2	2	0%	1.52	2	Sidewalk AB	2.9%
	Total	**1 Block**	**2.23E+05**	**2.73E+04**	**1.23E+02**	**2.38E+06**	**3.08E+06**								
East Kentucky	HMA (overlay)	1 Block	9.53E+04	1.21E+04	6.11E+01	1.09E+06	3.46E+06	10.0	7.6	3	0%	3.70	3	Street Top Layer	38.1%
	Aggregate, Crushed	1 Block	5.14E+04	9.09E+03	1.96E+01	7.92E+05	0.00E+00	15.0	33.0	2	0%	3.70	3	Street AB	20.5%
	PCC	1 Block	4.63E+04	4.28E+03	2.53E+01	3.57E+05	0.00E+00	20.0	15.2	2	50%	0.91	2	Curb & Gutter Surface	18.5%
	Aggregate, Crushed	1 Block	3.90E+03	6.91E+02	1.49E+00	6.02E+04	0.00E+00	15.0	15.2	2	0%	0.91	2	Curb & Gutter AB	1.6%
	Planting	1 Block	6.39E+01	3.59E+01	2.19E-01	2.58E+03	0.00E+00	5.0	NA	6	0%	1.83	2	Landscape	0.0%
	PCC	1 Block	4.66E+04	4.31E+03	2.55E+01	3.60E+05	0.00E+00	20.0	9.2	2	50%	1.52	2	Sidewalk Surface	18.6%
	Aggregate, Crushed	1 Block	6.51E+03	1.15E+03	2.48E+00	1.00E+05	0.00E+00	15.0	15.2	2	0%	1.52	2	Sidewalk AB	2.6%
	Total	**1 Block**	**2.50E+05**	**3.16E+04**	**1.36E+02**	**2.76E+06**	**3.46E+06**								

Table 120. Itemized Impacts of The Complete Street Option During the Analysis Period for Materials, Transportation, and Construction Stages- Kentucky Avenue

	CS Element	Material	GWP [kg CO2e]	POCP [kg O3e]	PM2.5 [kg]	PED (Total) [MJ]	PED (Non-Fuel) [MJ]	Service Life (yrs)	# per Block	Length (m)	Width (m)	Area of the Element (m2)	% of area that is replacing conventional treatment	Total Mass/Area /Length/Count over that of the CS element in the CS tab
West Kentucky	Coloring Lanes	Paint (area)	9.90E-03	1.22E-01	9.05E-07	1.60E-02	0.00E+00	3	1	270	2.13	576	0%	576
	Curb Extension	PCC on AB	4.88E+03	4.91E+02	2.59E+00	4.13E+04	0.00E+00	15	3	8	2.44	20	100%	59
	Raising the Intersection to Sidewalk Grade	HMA (overlay)	1.08E+03	1.36E+02	6.89E-01	1.23E+04	3.91E+04	10	1	10	3.00	29	0%	29
	Raised Bicycle Buffer	HMA (overlay)	2.24E+01	2.83E+00	1.44E-02	2.56E+02	8.14E+02	10	2	8	NA	NA	0%	16
	Buffered Cycle Track	HMA (overlay)	8.48E-04	1.04E-02	7.76E-08	1.37E-03	0.00E+00	3	2	270	0.30	82	100%	165
	Total (for 1 Block)		**5.98E+03**	**6.30E+02**	**3.30E+00**	**5.38E+04**	**3.99E+04**							
East Kentucky	Coloring Lanes	Paint (area)	1.98E-02	2.44E-01	1.81E-06	3.20E-02	0.00E+00	3	2	270	2.13	576	0%	1152
	Planted Furniture Zone	Planting	3.24E+01	6.73E+00	4.11E-02	4.83E+02	0.00E+00	5	1	250	2.00	500	100%	500
	Raised Bicycle Buffer	HMA (overlay)	7.56E+02	9.57E+01	4.85E-01	8.64E+03	2.75E+04	10	2	270	NA	NA	0%	540
	Buffered Cycle Track	HMA (overlay)	8.48E-04	1.04E-02	7.76E-08	1.37E-03	0.00E+00	3	2	270	0.30	82	100%	165
	Total (for 1 Block)		**7.88E+02**	**1.03E+02**	**5.26E-01**	**9.13E+03**	**2.75E+04**							

Appendix F: Neighborhood Information from CalEnviroScreen

Table 121. Summary of percentile rankings for environmental and public health burdens and populations for neighborhoods near complete streets from CalEnviroScreen

Complete Street	Census tract	Neighborhood ID number	0.5 or 2.0 mile distance	CalEnviroScreen percentile ranking (%)	Population
San Fernando St.					
	95110	6085500300	0.5	55-60	3140
	95110	6085500800	0.5	60-65	2600
	95112	6085501000	0.5	70-75	4769
	95192	6085500901	0.5	55-60	3723
	95112	6085501200	0.5	60-65	4186
	95128	6085502102	2	55-60	7469
	95126	6085502002	2	70-75	4887
	95128	6085502001	2	50-55	5022
	95126	6085500500	2	30-35	5275
	95050	6085505203	2	55-60	4809
	95110	6085505100	2	65-70	3027
	95110	6085500300	2	55-60	3140
	95126	6085500400	2	40-45	2369
	95126	6085500600	2	35-40	4586
	95126	6085501900	2	50-55	4641
	95125	6085502302	2	10-15	2826
	95125	6085502301	2	30-35	3245
	95126	6085502201	2	25-30	6260
	95125	6085503121	2	70-75	4499
	95112	6085503122	2	85-90	3449
	95112	6085503112	2	70-75	4025
	95122	6085503105	2	90-95	2484
	95122	6085503117	2	75-80	3120
	95122	6085503110	2	80-85	4618
	95116	6085501501	2	75-80	4278
	95116	6085501402	2	60-65	2947
	95116	6085501401	2	75-80	3295
	95112	6085501200	2	60-65	4186
	95131	6085504318	2	85-90	5265
	95133	6085503601	2	85-90	2992
	95133	6085504319	2	70-75	6936
	95133	6085503709	2	65-70	5088
	95116	6085503707	2	50-55	5462
	95116	6085503602	2	80-85	4741
	95116	6085503710	2	70-75	3599
	95116	6085503711	2	60-65	4763
	95122	6085503105	2	90-95	2488

Complete Street	Census tract	Neighborhood ID number	0.5 or 2.0 mile distance	CalEnviroScreen percentile ranking (%)	Population
	95110	6085500300	2	55-60	3140
	95112	6085501101	2	55-60	4074
	95112	6085501000	2	70-75	4769
	95110	6085500800	2	60-65	2600
	95116	6085501502	2	70-75	4549
	95110	6085503113	2	75-80	4760
	95112	6085503112	2	70-75	4025
Franklin Blvd.					
	95822	6067003501	0.5	50-55	2629
	95820	6067003600	0.5	65-70	2826
	95818	6067002500	0.5	10-15	1587
	95820	6067003700	0.5	75-80	4219
	95822	6067003501	2	50-55	2629
	95818	6067002400	2	30-35	4387
	65818	6067002200	2	90-95	4004
	95818	6067002300	2	35-40	3156
	95818	6067002000	2	85-90	2376
	95816	6067001500	2	30-35	4329
	95817	6067001800	2	70-75	4686
	95817	6067001700	2	55-60	4794
	95822	6067003502	2	50-55	2916
	95822	6067004100	2	65-70	5015
	95823	6067004903	2	70-75	6740
	95823	6067004701	2	85-90	3303
	95823	6067004702	2	90-95	4945
	95824	6067004601	2	75-80	7614
	95824	6067003202	2	60-65	5052
	95820	6067004401	2	75-80	4122
	95820	6067002900	2	55-60	4499
	95819	6067001600	2	20-25	5421
Kentucky Ave.					
	95776	6113011206	0.5	60-65	7329
	95695	6113010901	0.5	40-45	5311
	95776	6113010800	0.5	55-60	3881
	95695	6113011001	2	35-40	6464
	95776	6113011206	2	60-65	7329
	95776	6113010800	2	55-60	3881
	95695	6113011002	2	10-15	3093