SafeTREC Safe Transportation Research & Education Center

Performance Measures for Complete, Green Streets: Initial Findings for Pedestrian Safety along a California Corridor

Rebecca L. Sanders, SafeTREC,
Elizabeth Macdonald and Alia Anderson,
University of California, Berkeley, and
David R. Ragland and Jill F. Cooper, SafeTREC

2011
RR-2011-4 http://www.safetrec.berkeley.edu

Performance Measures for Complete, Green Streets: Initial Findings for Pedestrian Safety along a California Corridor

Rebecca L. Sanders*
rebeccasanders@berkeley.edu
University of California, Berkeley, Safe Transportation Research and Education Center
2614 Dwight Way, #7374
Berkeley, CA 94720
Tel: (510) 316-5940
Fax: (510) 643-9922

Elizabeth Macdonald
emacdon@berkeley.edu
University of California, Berkeley
406B Wurster Hall
Berkeley, CA 94720
Tel: (510) 643-3765
Fax: (510) 642-1641

Alia Anderson
aliadanderson@yahoo.com
University of California, Berkeley
406B Wurster Hall
Berkeley, CA 94720-1850

David R. Ragland
cooperj@berkeley.edu
University of California, Berkeley, Safe Transportation Research and Education Center
2614 Dwight Way, #7374
Berkeley, CA 94720
Tel: (510) 643-4259
Fax: (510) 643-9922

Jill F. Cooper
cooperj@berkeley.edu
University of California, Berkeley, Safe Transportation Research and Education Center
2614 Dwight Way, #7374
Berkeley, CA 94720
Tel: (510) 643-4259
Fax: (510) 643-9922

*corresponding author

Paper submitted for presentation at the 89th Annual Meeting of the Transportation Research Board, Washington D.C., January 2011 and publication in the Transportation Research Record, Journal of the Transportation Research Board

Word count: 7,052 words (5,802 words, 4 tables, 1 graph)

Performance Measures for Complete, Green Streets: Initial Findings for Pedestrian Safety along a California Corridor

Abstract

This paper reports on research conducted by the Safe Transportation Research and Education Center and sponsored by the California Department of Transportation ("Caltrans") to establish performance measures for pedestrian and bicycle safety and mobility along urban arterials. Although historically focused on motorized vehicle mobility, Caltrans has recently joined in a national trend to incorporate non-motorized transportation and community-level outcomes into transportation decision-making frameworks, an approach known as "Complete Streets." Recognizing that its current performance measurement system does not reflect this shift, Caltrans worked with researchers at the University of California, Berkeley to create new measures that more accurately gauge its progress toward these objectives. This paper discusses a field test of the validity and ease of application of the proposed performance measures for pedestrian safety. The test corridor was San Pablo Avenue, a 9.5-mile, multi-jurisdictional State Route in Northern California. While the researchers developed the performance measures based on a broad literature and best-practice review, the field-test determined that most of the initial performance measures for pedestrian safety require adjustments to improve validity and facilitate their broad adoption by Caltrans. This paper demonstrates the value of small-scale field-testing of performance measures before their adoption, particularly for subject areas with little institutional measurement history, like pedestrian and bicyclist safety and mobility. The paper concludes with discussion of the next steps of the performance measures development process and future research on the topic.

INTRODUCTION

Communities throughout the United States are rethinking street design in their downtowns and around their neighborhoods. Citing the adverse effects of high volumes of motorized traffic (e.g., decreased roadway safety, walkability, and bikability, and increased air and water pollution levels due to vehicle emissions), many communities desire transportation corridors that support local needs as well as throughput needs, and that safely accommodate multiple travel modes. Although efforts to enhance the quality of life within communities are increasingly supported by city planners, designers, transportation engineers, and public health practitioners, professionals lack a framework to comprehensively measure progress toward this broad objective. Recognizing this gap within their measurement system, the California Department of Transportation sponsored research at the University of California, Berkeley to develop such a framework.

Simultaneously, there is growing direction from the federal and state government for transportation agencies to be more accountable for funds and to provide defensible measures of effectiveness. State departments of transportation routinely use performance measures to assess their transportation systems, but assessment is generally based in the traditional highway engineering perspective of providing for automobiles, or is limited to monitoring whether departmental goals are achieved cost effectively or generate quantifiable net benefits. Although corridor design elements that support livable and sustainable communities have been identified through research, few defensible performance measures exist for assessing their effects on user safety, multimodal mobility, and environmental quality; certainly, no comprehensive framework of such measures presently exists.

This paper reports on the initial findings from field research aimed to create such a performance measurement framework to assist transportation agencies in assessing allocation of funds and efforts to enhance pedestrian and bicycle safety and mobility. Based upon defensible research findings and best practices, the framework was created specifically for urban arterials, which constitute 26% of the urban roadway network in California and carry high amounts of local traffic, particularly pedestrians and bicyclists, due to their density of attractions such as businesses, restaurants, and stores. Although designed specifically for Caltrans, the framework is adaptable to arterial roadways throughout the U.S., and usable by local agencies aspiring to create multimodal, sustainable streets.

The framework is strongly influenced by national Complete Streets principles, which urge that transportation facilities be "planned, designed, operated, and maintained to provide safe mobility for all users, including bicyclists, pedestrians, transit riders, and motorists appropriate to the function and context of the facility" *(1)*. The framework was also shaped by the Green Streets movement, which advocates for sustainable street design that maximizes permeable surfaces, tree canopy, and landscaping elements in order to capture and filter stormwater and increase urban green space *(2)*. While the framework covers several areas, this paper presents only the findings for pedestrian safety.

The UC Berkeley project has operated in three phases. Phase I involved a broad literature review of research on transportation corridor roadside design features and their effects on user safety and behavior, health, community and economic vitality, and the environment. Phase II included a review of performance measures in theory and practice, a review of policies and plans that guide Caltrans' project selection and design, and the development of the proposed *Complete, Green Streets Performance Measures Framework.* Phases I and II are only briefly described in the following section. The full reports for both Phase I and II can be found online at http://escholarship.org/uc/item/12047015, and http://escholarship.org/uc/item/6q85b8d6, respectively.

This paper elaborates on the initial findings from Phase III, in which data to measure and test the proposed performance measures was gathered and is being analyzed via regression modeling. This field-test of the proposed performance measures is being used to test both their validity and ease of application. Both of these factors will be used to revise the performance measures and inform Caltrans' decision as to whether each will be implemented as part of their broader performance measurement system.

BACKGROUND

This section briefly describes the Phase I literature review and the development of the proposed performance measures during Phase II. The proposed performance measures for pedestrian and bicyclist safety are also listed in this section, along with an explanation of how they relate to Caltrans' current performance measurement system.

Overview of the Phase I Literature Review

The purpose of the Phase I literature review was to gather the latest scholarship and best practices on which the proposed *Complete, Green Streets Performance Measures* would be based. The literature review focused on the effects of transportation corridors' roadside design features on the following macro categories: pedestrian and bicyclist safety; pedestrian and bicyclist mobility; community and economic vitality; environmental sustainability; and public health. Literature searches were conducted in major transportation, economic, urban planning, and public health databases, and approximately 180 studies and best practices were reviewed. Although validity, replicability, and ability of findings to be generalized were considered in the review, some of the selected studies had small sample sizes and/or were less robust than the most rigorous science demands. While the authors relied heavily on the more robust studies in developing the proposed *Complete, Green Streets Performance Measure Framework*, the smaller studies were used if there were no better studies available on the specific subject matter (for example, there is relatively little research on the effects of roadside design features on economic vitality). Validity and quality of the measures will be ultimately controlled through Phase III field testing.

Key findings for pedestrian and bicyclist safety included:

- Higher driving speeds were found to be more associated with vehicle crashes and fatalities than slower speeds *(3)*. Higher speeds also increase the chance that pedestrians and cyclists will suffer serious injuries if they are hit *(4)*.
- Street sections with landscaping and amenities, where low speed is communicated through design, are often found to have fewer vehicular collisions and fewer pedestrian and bicyclist injuries and fatalities *(5-6)*.
- Pedestrian crosswalk installation has been generally positively associated with increased usage by pedestrians and slightly decreased driver speed approaching the intersection, particularly if ancillary traffic safety treatments are installed *(7-9)*.
- To help prevent the risk of driver misunderstanding at crosswalks, marked crosswalks at unsignalized locations should be installed with supplementary measures such as flashing lights, in-pavement lighting, or red beacons on all multi-lane roadways and in areas with high volumes of or fast-moving traffic *(10-15)*.

- Pedestrian countdown signals have been positively associated with increased pedestrian compliance with signalization, leading to safer crossing behavior *(16)*.
- Leading pedestrian intervals have been associated with reduced crash rates at intersections allowing right turns on red *(17)*.

Overview of the Phase II Review of Plans, Policies and Legislation

The second phase of the project involved the development of the proposed *Complete, Green Streets Performance Measures* for Caltrans, and, as such, necessitated an examination of the many layers of policy, planning, and legislation affecting the Department. The Phase II review found a growing body of adopted material, ranging from California State Senate Bill 375 (*Regional Planning for Greenhouse Gas Reduction*) to Caltrans' Strategic Plan, which indicates the State's intention and responsibility to address pedestrian and bicyclist safety and mobility, as well as environmental issues, through more community-serving transportation facility design *(18-19)*. There has been a particular focus on Complete Streets principles, building upon federal and state policies that promote the development of multimodal, community-serving streets – notably the 2007 California Complete Streets legislation that requires a city or county to identify how it provides for the routine accommodation of all roadway users, including pedestrians, bicyclists, individuals with disabilities, seniors, transit riders, and motorists, when the circulation element of a general plan is updated *(20)*. In addition, Caltrans' Deputy Directive 64-R1 Complete Streets recognizes "bicycle, pedestrian, and transit modes as integral elements of the transportation system," and that Caltrans "provides for the needs of (all) travelers…in (all) planning, programming, design, construction, operations, and maintenance activities and products on the State highway system" *(1)*. This political and professional momentum heavily influenced the development of the proposed framework, as did best practices in performance measurement from around the United States.

Caltrans' Current Use of Performance Measures

To monitor the state's transportation system, Caltrans currently uses performance measures based on five high-level goals related to safety, mobility, delivery, stewardship, and service *(19)*. Each goal is accompanied by objectives that have numerical targets and timeframes coordinated with the Strategic Plan that Caltrans adopts every five years. At the end of each fiscal year, performance is measured and compared with the results of previous years, allowing Caltrans to gauge overall progress toward objectives. Caltrans' current measurement system focuses on motorized travel: it contains no objectives or measures concerned with the safety and mobility of non-motorized travelers, and none concerned with environmental quality, other than litter clean-up. Clearly, momentum exists within Caltrans for taking a more holistic approach to maintaining the transportation system; however, this vision has not been comprehensively adopted.

The proposed *Complete, Green Streets Performance Measure Framework* fills the gap for pedestrian and bicycle safety and mobility, and contributes to evaluating environmental stewardship (more research is needed before an entire range of performance measures can be formed for this area). The authors note that transit, although an essential element of a complete street, was excluded from this proposal because of the need to focus the scope. By combining the new framework with its existing measures, the Department would take a major step toward creating a meaningful and comprehensive system to measure progress toward a multimodal and community-serving transportation network.

Proposed Complete, Green Streets Objectives and Measures

To facilitate incorporation of the new objectives and measures, the proposed framework was developed using Caltrans' existing structure and format. The proposed objectives and performance measures, labeled "CGS objectives" (for Complete, Green Streets), and "PM", respectively, are listed as they would be if incorporated into Caltrans' Strategic Plan. In several places, an "X" is used as a placeholder for a year or target where more work is needed before a finite target year or level (i.e., reduce injury rate to 1 per 1 million vehicle miles traveled) could be set.

The proposed objectives and measures for pedestrian and bicyclist safety are listed in Table 1 on the following page. Note that these performance measures are those tested in Phase III of the project, and are not presented as a finalized set. The research team, together with Caltrans, decided to focus on the safety and mobility goals for the third phase of the project; the proposed performance measures for the stewardship and service goals will be tested at a later date and are therefore not described in this paper. The proposed mobility measures will be tested this fall and are therefore listed in the "next steps" section of this paper.

TABLE 1 Proposed Complete, Green Streets Objectives and Measures for Pedestrian Safety on Caltrans Urban Arterials

CALTRANS SAFETY GOAL: Provide the safest transportation system in the nation for users and workers.	
CGS Objectives	CGS Performance Measures
1.1: By 2012, reduce the annual pedestrian and bicycle injury and fatality rates to the following levels, and continuously reduce annually thereafter with the goal of having the lowest rates in the nation: – Pedestrian fatality rate target: X per X walking trips. – Pedestrian injury rate target: X per X walking trips. – Bicyclist fatality rate target: X per X bicycling trips. – Bicyclist injury rate target: X per X bicycling trips.	PM 1.1a: Rate of pedestrian fatalities per walking trips. PM 1.1b: Rate of pedestrian injuries per walking trips. PM 1.1c: Rate of bicyclist fatalities per bicycling trips. PM 1.1d: Rate of bicyclist injuries per bicycling trips.
1.2: By 2017, double the percentage of people who feel safe using non-motorized modes on urban arterials. By 2022, increase this percentage to XX%.	PM 1.2: Percentage of Californians who feel safe using non-motorized modes on urban arterials.
1.3: By 2012, all Caltrans urban arterial projects (new expenditures) are designed to increase safety for non-motorized users in accordance with Complete Streets principles. By 20XX, all Caltrans urban arterials are designed for safety according to these principles.	PM 1.3a: Percent of signalized intersections along urban arterials with marked crosswalks and one or more of the following: countdown signals, leading pedestrian intervals, bulb-outs, or pedestrian refuge islands. PM 1.3b: Percent of unsignalized 4-way (multilane) intersections along urban arterials with marked crosswalks and one or more of the following: HAWK signal*, yield to pedestrian signage, user-activated overhead warning lights. PM 1.3c: Percent of urban arterial intersections with one or more of the following improvements geared toward bicyclists: bike box*, painted bicycle lane through the intersection*, bicycle signal, bicycle detectors, bicycle left turn lane. PM 1.3d: Percent of urban arterials on which the 85th percentile driving speed is no greater than 25 mph.
1.4: By 2012, annually reduce the number of pedestrian and bicycle hotspots (high collision concentrations) on urban arterials.	PM 1.4a: Overall number of pedestrian collision hotspots on urban arterials. PM 1.4b: Overall number of bicycle collision hotspots on urban arterials.

PHASE III METHODOLOGY

The third phase of the project has focused on gathering data to field-test the proposed *Complete, Green Streets Performance Measures* for safety and mobility. This section describes the field study area and the data gathering process.

Study Area

The research team selected San Pablo Avenue, a 9.5-mile, multi-jurisdictional corridor in the East San Francisco Bay of California, as the test corridor for the project. San Pablo Avenue is a historic State Route (123) that acts as an urban arterial, so it is under the jurisdiction of Caltrans as well as several cities in the area. This guaranteed that there would be some consistency in the street layout and operation, but also a variety of design conditions that may affect pedestrians and bicyclists, such as landscaping, context sensitive paving, public seating, etc. Table 2 describes some of the variety in the street conditions along San Pablo Avenue.

TABLE 2 Description of Street and Intersection Conditions along San Pablo Avenue

Intersection Conditions: Crossings	• Sixty-two percent of all intersections had at least three crosswalk legs (including a sidewalk); only 24% had a crosswalk on each leg. • Thirty-seven percent of all intersections had at least one pedestrian signal (countdown or not); twenty-seven percent of all intersections had pedestrian signals in at least 3 directions. • Fourteen percent of intersections had a crossing speed of over 3.5 feet/second in at least one direction.
Intersection Conditions: Other	• Approximately 63% of intersections had at least one dedicated left turn lane. • Approximately 60% of intersections had on-street parking up to the intersection on at least one side. • Twelve percent of intersections had pedestrian signage.
Sidewalk Conditions	• Over 53% of sidewalks were between 5' and 7'11" wide. • Only 15% of street segments had significant impediments. Forty-four percent of segments had no impediments.
Segment Conditions: Landscaping	• Fifty percent of the street segments had regularly spaced street trees on both sides; approximately 65% had regularly spaced trees on at least one side. • Approximately 62% of the street segments had gardens or planters on at least one side. • Nearly 70% of street segments had landscaped medians; only one median had no landscaping.
Segment Conditions: Other	• Approximately 40% of street segments had at least one trashcan • Around 25% of street segments had public seating on at least one side. • Nearly 70% of street segments had time-restricted parallel parking on at least one side. • Around 37% of street segments had 1-2 retail locations on at least one side; approximately 23% of street segments had at least 3 retail locations on either side. • Approximately 11% of the corridor had 5 or more driveways on at least one side of the street. There was an average of 2 driveways per side of the street. • School zones were present along 20% of street segments.

Data Gathering & Processing

A checklist was developed to facilitate gathering the data needed to test the proposed performance measures. The checklist also included elements needed to perform a multimodal LOS assessment on the corridor. This was done in order to double-check any conclusions the research team could draw about the framework with an accepted LOS method. The San Francisco Pedestrian Environmental Quality Index was also used for the facility analysis, as it measures some of the necessary information to test the proposed performance measures. In addition, the research team reviewed the pedestrian and bicycle plans of each city and county with jurisdiction over San Pablo Avenue, and added the most common elements of the plans to the facility checklist as a way to evaluate the impact of policies on the design of the corridor.

Data was gathered from October, 2009 – June, 2010, depending on the weather. The lead author and two undergraduate researchers drove to the research site and collected the data on paper forms, using standard engineering measuring wheels and stopwatches to enable measurement of distance and time. There are approximately 180 intersections along the test corridor, and the data was gathered for each intersection and its corresponding southern roadway section (both sides of the street segment were measured separately). In this way, data for each intersection and roadway section were attached to a unique ID in the analysis. The researchers spent about 15-20 minutes gathering the data for each intersection and corresponding roadway section. After the data was gathered manually, it was input into a Microsoft Excel™ spreadsheet and checked for accuracy through a combination of Google Maps Street View™ and Google Earth™. When the data was questionable and could not be corroborated through online tools, new data was obtained through a second trip to the site.

The original data set contained 181 intersections along San Pablo Avenue as determined by each city's GIS files, and researchers at SafeTREC coded each intersection with the total number of pedestrian and bicycle injuries and fatalities from the years 1997-2007. The crashes were determined from the California Highway Patrol Statewide Integrated Traffic Records System (SWITRS), and were coded to the nearest intersection along the corridor. When gathering the physical data for analysis, the researchers were unable to match some of the intersections in the GIS files to intersections on the ground, resulting in the deletion of 11 intersections from the data set; 170 intersections remained.

After the data set was finalized in Excel, the file was transformed into a database file for analysis using the statistical software package STATA. The first stage of analysis focused on pedestrian safety only. Due to the low number of pedestrian fatalities in the dataset (n=9), the research team elected to combine the pedestrian injuries and fatalities for the outcome variable in the regression analysis. Although the data is count data, it did not fit the traditional Poisson distribution, given that the variance was several times greater than the mean. A comparison of distributions suggested that a negative binomial distribution was more appropriate for regression (corroborated by a goodness-of-fit test in STATA). In order to account for exposure, pedestrian volumes were estimated according to a model based on the work of Schneider et al. *(21)*, which was derived using data including several of this study's intersections.

Table 3 describes the range and distribution of the various street treatments variables tested in the pedestrian crash model. The variables were entered one by one in the negative binomial regression model, keeping only those with a p value of less than 0.10. To control for collinearity, variables were compared for correlation and only one variable of highly correlated pairs was entered into the regression model. While the regression model was able to clearly demonstrate insignificance for some of the proposed performance measures, a final version is not presented in this paper due to the need for further testing.

TABLE 3 Frequency of Various Street Treatments & Events along San Pablo Avenue

Description	Mean	Range / SD
Combined pedestrian incidents	1.52	Range: 0 to 10 SD: 2.14
On-street parking up to intersection – east (west)	0.59 (0.62)	Range: 0 to 1 [0 = no on-street parking; 1 = on-street parking]
Percent sidewalk “fair or better” – east (west)	95.36 (93.50)	Range: 30 to 100 (10 to 100) SD: 11.11 (13.79)
Percent sidewalk ADA compliant – east (west)	96.14 (95.65)	Range: 0 to 100 (40 to 100) SD: 11.17 (10.74)
Context sensitive crosswalk legs		Range: 0 to 4
Trashcans – east (west)	0.50 (0.62)	Range: 0 to 4 (0 to 5) SD: 0.72 (0.94)
Pedestrian trips	9361.48	Range: 4987 to 55,436 SD: 6292.89
Driveways – east (west)	2.05 (1.81)	Range: 0 to 12 (0 to 10) SD: 2.14 (2.07)
Street trees – east (west)		Range: 0 to 2 [0 = no street trees; 1 = sporadic street trees; 2 = regular street trees]
Gardens/planters – east (west)		Range: 0 to 1 [0 = no gardens/planters; 1 = gardens/planters]
Public seating – east (west)		Range: 0 to 1 [0 = no public seating; 1 = public seating]
Sidewalk buffer – east (west)		Range: 0 to 3 [0 = no buffer; 1 = bicycle lane; 2 = unrestricted parallel parking; 3 = time-restricted parallel parking]
Storefronts – east (west)		Range: 0 to 2 [0 = no storefronts; 1 = 1 or 2 storefronts; 2 = 3 or more storefronts]
Public art or historical site – east (west)		Range: 0 to 1 [0 = no public art or historical sites; 1 = public art or historical sites]
Graffiti – east (west)		Range: 0 to 1 [0 = little to no graffiti; 1 = graffiti]
Litter – east (west)		Range: 0 to 1 [0 = little to no litter; 1 = litter]
Pedestrian-scaled lighting – east (west)		Range: 0 to 3 [0 = no lighting; 1 = private lighting; 2 = public lighting; 3 = private & public lighting]
Construction – east (west)		Range: 0 to 1 [0 = no construction; 1 = construction]

Abandoned buildings – east (west)		Range: 0 to 1 [0 = no abandoned buildings; 1 = abandoned buildings]
Left turns at intersection	0.91	Range: 0 to 2 SD: 0.80
Raised median		Range: 0 to 1 [0 = no median; 1 = median]
Regular median width	9.44	Range: 4 to 18 SD: 5.93
Median width when left turn lane is present	2.53	Range: 0 to 9 SD: 2.16
Landscaping on median		Range: 0 to 1 [0 = no landscaping; 1 = landscaping]
Median landscaping type		Range: 0 to 7 [0 = none; 1 = grass; 2 = shrubs; 3 = trees; 4 = grass, shrubs; 5 = grass, trees; 6 = shrubs, trees; 7 = grass, shrubs, trees]
Passability of median		Range: 0 to 1 [0 = not passable; 1 = passable]
Mid-block crossing		Range: 0 to 1 [0 = no mid-block crossing; 1 = mid-block crossing]
Mid-block crossing sign		Range: 0 to 1 [0 = no signage; 1 = signage]
Standard crosswalks	2.69	Range: 0 to 5 SD: 1.04
Ladder crosswalks	0.17	Range: 0 to 4 SD: 0.73
Crosswalks (either type)	2.77	Range: 0 to 5 SD: 0.99
Pedestrian signals with countdowns	0.39	Range: 0 to 5 SD: 1.15
Pedestrian signals without countdowns	0.79	Range: 0 to 5 SD: 1.39
Pedestrian signals (either type)		Range: 0 to 1 [0 = no pedestrian signal; 1 = pedestrian signal(s)]
Intersection legs > 4		Range: 0 to 1 [0 = four or fewer legs; 1 = more than four legs]
Crosswalk length - north	81.38	Range: 71 to 152 SD: 11.38
Crosswalk length – south	79.54	Range: 24 to 156 SD: 9.56
Crosswalk length – east	44.49	Range: 21 to 113 SD: 17.48
Crosswalk length – west	48.05	Range: 21 to 135 SD: 21.93

Crossing speed over 3.5 feet/second		Range: 0 to 1 [0 = crossing speed under 3.5 ft/sec; 1 = crossing speed over 3.5 ft/sec]
Average crosswalk length – north/south	80.46	Range: 62.5 to 138 SD: 9.0
Average crosswalk length – east/west	46.47	Range: 21 to 117.5 SD: 18.47
Right turns on red prohibited		Range: 0 to 2
Intersection traffic-calmed		Range: 0 to 1 [0 = no traffic calming; 1 = traffic calming]
Pedestrian signs at intersection		Range: 0 to 1 [0 = no pedestrian signs; 1 = pedestrian signs]
Vehicle speed posted		Range: 0 to 1 [0 = no speed limit sign; 1 = speed limit sign]
School zone		Range: 0 to 1 [0 = no school zone; 1 = school zone]
Sidewalk width – east (west)		Range: 0 to 3 [0 = less than 5 feet; 1 = 5 to 7 feet, 11 inches; 2 = 8 to 12 feet; 3 = over 12 feet]
Sidewalk impediments – east (west)		Range: 0 to 3 [0 = no sidewalk; 1 = no impediments 2 = few impediments; 3 = significant impediments]
Sidewalk obstructions – east (west)		Range: 1 to 3 [1 = no obstructions; 2 = temporary obstructions; 3 = permanent obstructions]

Once the data were analyzed, the proposed performance measures were judged for their validity and ease of application. Validity was determined differently for the various performance measures. For measures that examine relationships between design elements and safety (measures 1.3a-d), validity was assessed by whether or not the measurement proved significantly related to pedestrian safety in the crash model. For measures that examine quantities of incidents (measures 1.1a-b and 1.4a), validity was determined by whether or not that quantity made sense as the selected measurement of the subject area. Ease of application was determined after evaluating the amount of time and effort the task took the research team to complete.

FINDINGS

This section elaborates on the findings regarding the validity and ease of application of the pedestrian safety-related performance measures proposed in Phase II of the project.

CGS Performance Measures 1.1a - 1.1b: Rates of Injury and Fatality

The guiding objective for performance measures 1.1a and 1.1b was modeled after Caltrans' objective for vehicular safety:

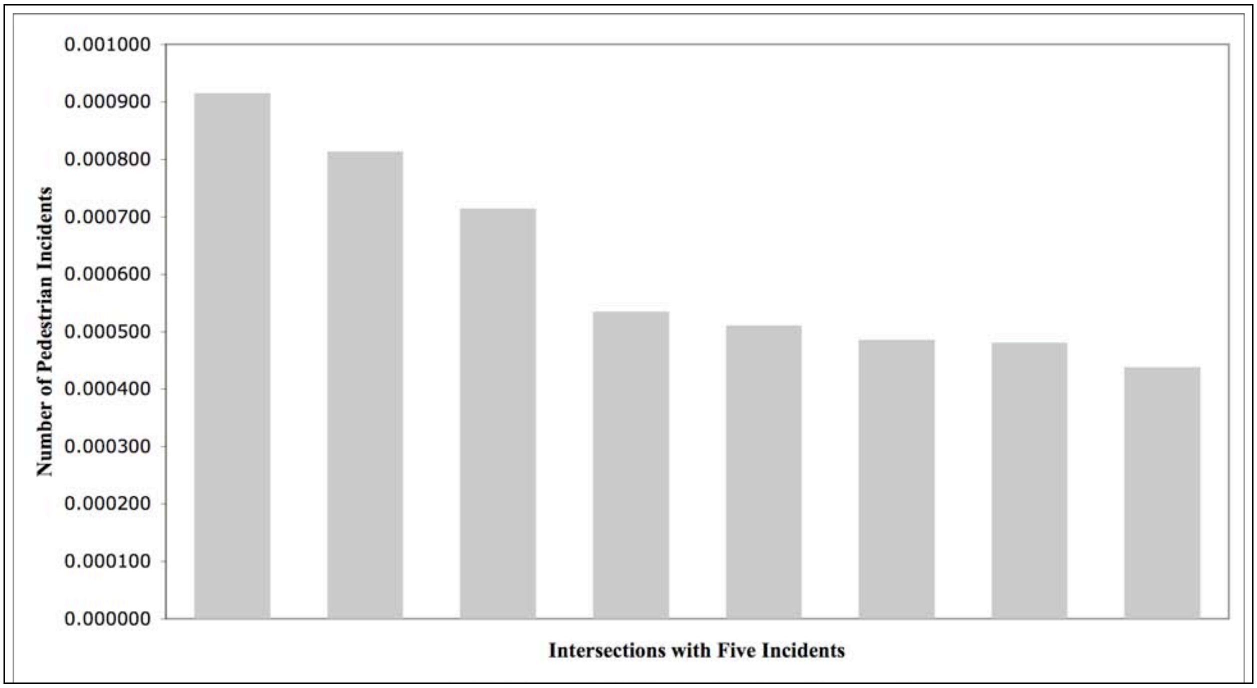
By 2012, reduce the annual pedestrian and bicycle injury and fatality *rates to the following levels, and continuously reduce annually thereafter with the goal of having the lowest rates in the nation.

– Pedestrian fatality rate target: X per X walking trips.
– Pedestrian injury rate target: X per X walking trips.
– Bicyclist fatality rate target: X per X bicycling trips.
– Bicyclist injury rate target: X per X bicycling trips.
*Rates not set due to the need to establish a baseline number.

It is well-established that accounting for exposure is the most accurate way to assess pedestrian risk *(22-23)*. Measuring the number of crashes without accounting for exposure could give the impression that a reduction in crashes is due to safer behavior on the roadway, when in reality, the number of pedestrians could be declining. Similarly, measuring only overall numbers may give the impression that an intersection with zero crashes is very safe, when in reality, it could be so unsafe that no one dare cross it. Both of these scenarios reinforce the need to measure incidence rate, rather than a cumulative incident number, to accurately gauge pedestrian risk. However, gathering pedestrian volumes is a task that transportation agencies may not prioritize, so pedestrian safety may or may not be measured through other ways. For example, Caltrans currently measures combined traveler safety: pedestrian and bicycle fatalities are combined with vehicle fatalities, and then divided by 100 million VMT in order to gauge the rate of collisions on state highways (including those that run through cities as urban arterials) *(19)*. Whether there were 10 or 1,000 pedestrian fatalities, the actual picture of pedestrian safety would be unclear due to having been combined with other modes. Although Caltrans' current Strategic Highway Safety Plan proposes to measure pedestrians and bicyclists separately from motorized vehicles, the SHSP proposes measuring overall amounts, which, without exposure, will not allow California to truly measure risk to pedestrians or bicyclists *(24)*.

Proposed CGS performance measures 1.1a (*rate of pedestrian fatalities per walking trips*) and 1.1b *(rate of pedestrian injuries per walking trips*) have the potential to provide a much more specific and accurate picture of the risk pedestrians face on the roadway. To "test" these measures, the overall number of pedestrian injuries and fatalities were compared to the rate of injuries and fatalities per weekly intersection crossings (a proxy for pedestrian trips). As shown in Figure 1, intersections with the same number of incidents can have dramatically different crash rates. In this case, a person crossing the intersection with the highest rate has more than twice as much risk of being hit as a person crossing the intersection with the lowest rate. This demonstrates that a reliance on total number could wrongly suggest that certain intersections are safer or more dangerous than they actually are. For this dataset, fatalities and injuries were combined due to a low number of fatalities (n=9). Likewise, if Caltrans were to measure individual corridors in the future, performance measure 1.1a may be modified to measure both fatalities and injuries. However, in the case of a system-wide evaluation, it is recommended that separate performance measures are evaluated for pedestrian injuries and fatalities, in order to fully understand the level of each type of risk to pedestrians.

FIGURE 1 Rate of Pedestrian Fatalities & Injuries at San Pablo Avenue Intersections With Identical Fatality and Injury Counts, 1997-2007



PM1.1a & 1.1b Conclusions

Validity: The proposed performance measures evaluate the intended quantity, and are the most accurate measures for the subject area.

Ease of Application: The research team concluded that the ease of application for this performance measure is reasonably high. The data needed for these performance measures includes: 1) the number of incidents in the system, and 2) the corresponding number of pedestrian trips (or a proxy, such as the number of pedestrian crossings per intersection). The challenges to obtaining this data are explained below.

1) The number of incidents on Caltrans' roadways can be obtained through the CHP SWITRS database. The data must be filtered for pedestrian crashes and road type, and then separated by year and injury type before it can be summed; however, all of these functions can be done using readily available desktop software. The research team spent only a few hours doing this task for the research project; using database tools, this task can be scaled with minimal additional staff effort.
2) Pedestrian exposure data is difficult and expensive to gather. However, this project is currently testing the validity of using pedestrian count models in the place of on-the-ground pedestrian counts. Count models use geographic information and data from the U.S. Census to give estimates of pedestrian volumes that can be used as a proxy for actual exposure, facilitating the application of this performance measure.

CGS Performance Measure 1.2: Perceptions of Safety

This measure is currently being evaluated.

CGS Performance Measures 1.3a - 1.3d: Complete Streets

The guiding objective for performance measures 1.3a – 1.3d is:

By 2012, all Caltrans urban arterial projects (new expenditures) are designed to increase safety for non-motorized users in accordance with Complete Streets principles. By 20XX, all Caltrans urban arterials are designed for safety according to these principles.

The core of this objective, "accordance with Complete Streets principles," refers to the Complete Streets goal of providing "safe mobility for all users" *(1)*. While "safe mobility" may be simple enough to imagine, developing a succinct, practical performance measure for the concept has proven more difficult. Based on research showing the effect of vehicle speed and various street design treatments on pedestrian safety, the research team developed four performance measures to capture the essence of the objective *(5, 8-19)*.

The first measure, 1.3a, pertains to the *Percent of signalized intersections along urban arterials with marked crosswalks and one or more of the following: countdown signals, leading pedestrian intervals, bulb-outs, or pedestrian refuge islands.* San Pablo Avenue does not have any leading pedestrian intervals, so the validity of this part of the measure could not be tested. However, the remainder of the measure, separately (standard and high visibility crosswalks, pedestrian signals with and without countdowns, bulb-outs, and refuge islands) and in combination, was not found to be significant (cutoff of $p = 0.10$) in the regression model. At this time, it is not quite clear why this is, given past research that has found a combination of these treatments to enhance pedestrian safety *(8-11, 13)*. The research team is currently investigating the matter further. It is possible that parts of the measure, while perhaps beneficial for pedestrian safety, are counteracted by unmeasured forces. For example, upon further examination of the data, the researchers noted that pedestrian refuge islands were common in locations with right turn slip lanes, which have been found to negatively impact pedestrian safety *(27)*.

PM1.3a Conclusions

Validity: This performance measure must be revised before it can be recommended.
Ease of Application: Give that the measure may be modified significantly from its current state, an evaluation of the ease of application is not possible at this time.

The second measure, 1.3b, focuses on the *percent of unsignalized 4-way (multilane) intersections along urban arterials with marked crosswalks and one or more of the following: HAWK signal, yield to pedestrian signage, user-activated overhead warning lights.* HAWK signals are not currently allowed in California, so the effectiveness of this part of the measure could not be tested. However, as before, the remainder of the measure, separately (standard and high visibility crosswalks, pedestrian signage, and user-activated warning lights) and in combination, was not found to be significant in the regression model. Similar to the measure for signalized intersections, it is not clear why these aspects were insignificant; the research team is currently investigating the matter further.

PM1.3b Conclusions

Validity: This performance measure must be revised before it can be recommended.
Ease of Application: Give that the measure may be modified significantly from its current state, an evaluation of the ease of application is not possible at this time.

The third measure, pertaining to bicycle treatments, is currently being evaluated. The fourth measure, *percent of urban arterials on which the 85th percentile driving speed is no greater than 25 mph*, is based on research showing the non-linear relationship between risk of injury or death and vehicle speed *(5)*. Unfortunately for both the research and pedestrians along San Pablo Avenue, no sections of the corridor passed this performance measure, so it is unclear how it would have been related to pedestrian safety. This is due in part to a posted speed limit of 30 mph throughout the corridor, which influenced the average speed (just over 34 mph), and the 85th percentile speed (average of 37.5 mph). While it may seem that a measure seeking speeds around 25 mph does not fit a corridor with a 30 mph speed limit, it is precisely the danger to pedestrians from the average and 85th percentile speeds that necessitates some kind of acknowledgement of the risk inherent in the corridor's design speed.

PM1.3d Conclusions

Validity: This performance measure must be evaluated on a separate corridor before it can be recommended.

Ease of Application: The data needed for this performance measure is available through routine speed surveys along Caltrans corridors, thus enabling implementation of the measure.

CGS Performance Measures 1.4a: Hotspots

The final performance measure for pedestrian safety is guided by the objective:

By 2012, annually reduce the number of pedestrian and bicycle hotspots (high collision concentrations) on urban arterials.

PM 1.4a gauges the *overall number of pedestrian collision hotspots on urban arterials* as a way to ensure that high collision locations are specifically examined even when the location may have a lower rate of pedestrian collisions due to exposure. This mirrors Caltrans' practice with motorized vehicles. This measure was "tested" through evaluation of incidence rate versus overall number of incidents, similar to PM 1.1a and 1.1b. In this dataset, for example, the intersection with the 9th highest rate had the 3rd highest number of collisions. While the rate suggests that it should be a lower priority, it still merits attention given the total number of crashes.

PM1.4a Conclusions

Validity: The proposed performance measure evaluates the intended quantity and is the most appropriate measure for the subject area.

Ease of Application: The data needed for this performance measure is the SWITRS crash data – the same data needed for proposed performance measures 1.1a-b. The research team thus concludes that the ease of application for this performance measure is reasonably high.

LIMITATIONS OF THE RESEARCH

As this research is still in progress, care should be used in extending the performance measures evaluated and conclusions reached in this paper to other situations. In addition, it should be noted that, although the test corridor has nearly 200 intersections and a variety of conditions, the intersections cannot be assumed to be entirely independent due to being under the jurisdiction of Caltrans and carrying the same traffic for at least parts of the corridor.

CONCLUSIONS

This article presented the initial findings of the field-tests for the pedestrian safety components of the *Complete, Green Streets Performance Measures Framewo*rk being developed to provide Caltrans with the measures needed to monitor pedestrian and bicyclist safety and the environmental health of its urban arterials. The findings of the Phase III field tests suggest that several of the performance measures developed after Phase I and II of the project adequately measure pedestrian safety, and should be retained for future use. However, other measures should be revised and tested further before being recommended for use by Caltrans. Table 4 summarizes the conclusions about the proposed performance measures.

TABLE 4 Relative Validity and Ease of Application of the Performance Measures for Pedestrian Safety Proposed in Phase II of the Project

Relative Validity	**High**		• PM 1.1a-b: Rate of Pedestrian Injuries & Fatalities	• PM 1.4a: Pedestrian Hotspots
	Low (Requires adjustment)	• PM 1.3a-b: Complete Streets (Intersection Design)		
	Unknown Based on Field Test			• PM 1.3d: Complete Streets (85th Percentile Speed)
		Low (Requires adjustment)	**Medium (Potentially data intensive)**	**High**
		Relative Ease of Application		

Only one of the proposed performance measures falls into the optimal ‘High Validity’ & ‘High Ease of Application’ category. While the designation of “low validity” is not a final judgment, it does indicate that several of the measures require some form of adjustment before they can be recommended for use by Caltrans. This finding speaks to the risk of developing performance measures based solely on literature review, policy evaluation, and best practices, particularly for areas with little institutional measurement history and practice, like pedestrian and bicyclist safety. It also emphasizes the value of conducting even small-scale field-testing of proposed performance measures, through providing the opportunity for critical feedback on the validity and implementation potential of the measures.

In addition to needing to improve their validity, some of the performance measures described in this paper may be modified to improve their ease of implementation. It should also be noted that there are ways to ease the implementation of some of the proposed performance measures as they currently exist. Caltrans can continue to fund research that develops tools to facilitate data gathering for all types of analysis. This could include, for example, improved pedestrian count models and databases of critical street design information (e.g., width of sidewalks, presence of crosswalks, etc.). Such work could be carried out through existing partnerships with University Transportation Centers. In addition, Caltrans can make use of community volunteers and advocacy groups who may be willing to gather the information needed to evaluate aspects of safety and mobility. For example, volunteers were used to gather the data necessary to develop the pedestrian count model used in this paper *(21)*. While the research team has an opinion about the "relative ease of application" of the proposed performance measures, the final judgment belongs to the Caltrans employees who will be performing the analysis in the future.

Field testing proposed performance measures has been a critical step in the development of Caltrans' *Complete, Green Streets Performance Measures Framework for Urban Arterials.* Field tests revealed that performance measures based on the latest research may be neither valid nor easy to implement. While this is not a shocking finding, some organizations may wish to develop performance measures without expending the time or costs associated with field tests. It is possible, as was the case with this project, that their metrics will prove to be suboptimal. While this may be discovered early, particularly with issues related to ease of implementation, it may also be some time before issues are identified and performance measures are revised or discarded. This project demonstrates that relatively small-scale field tests can contribute significantly to the development of performance measures that are valid and easy to apply in practice.

NEXT STEPS

The next steps for the project include continuing to hone the pedestrian crash model and revise the proposed performance measures for pedestrian safety. In addition, the researchers will analyze the effectiveness of the measures for bicyclist safety, and for pedestrian and bicyclist mobility. These proposed performance measures include:

PM 1.2: Percentage of Californians who feel safe using non-motorized modes on urban arterials.

PM 1.3c: Percent of urban arterial intersections with one or more of the following improvements geared toward bicyclists: bike box[*]*, painted bicycle lane through the intersection*[*]*, bicycle signal, bicycle detectors, bicycle left turn lane.*

PM 1.4b: Overall number of bicycle collision hotspots on urban arterials.

PM 2.1a: On urban arterials, ratio of sidewalk mileage to centerline roadway mileage, bidirectionally.

PM 2.1b: On urban arterials, ratio of Class II bicycle facility mileage to centerline roadway mileage, bidirectionally.

PM 2.1c: On urban arterials, percentage of intersections that are ADA compliant.

PM 2.1d: Percentage of urban arterial projects designed as Complete Streets.

PM 2.1e: Number of pedestrian trips on urban arterials.

PM 2.1f: Number of bicycle trips on urban arterials.

Key to understanding the relationship between mobility and the facility data is the pedestrian and bicycle intercept survey that will be conducted in early fall 2010. As the proposed performance measures are analyzed for applicability and effectiveness, they will be put through the same field-testing process described in this paper. As was the case for the pedestrian safety measures, issues will be identified and addressed before the performance measures are recommended for use by Caltrans. In doing so, the researchers plan to deliver a valid and relatively easy to implement set of measures for Caltrans' *Complete, Green Streets Performance Measures Framework for Urban Arterials.* The research team aims to have the framework ready for adoption by spring 2011. At that time, Caltrans can begin to set targets and gather the data necessary to measure the performance of its network with regard to pedestrian and bicyclist safety and mobility.

The result of implementing the proposed *Complete, Green Streets Performance Measures Framework for Urban Arterials* should be a Caltrans roadway system that better accommodates pedestrians and bicyclists and contributes to environmental sustainability and community vitality through increased multimodal mobility, and ultimately, more holistic street design. While the objectives will naturally take time to be reached, the adjustment toward such a system provides taxpayers a way of holding the government accountable in their role as stewards of valued community spaces, and allows Caltrans to demonstrate significant leadership regarding livability within the transportation field.

ACKNOWLEDGEMENTS

The authors would like to thank SafeTREC researchers Hannah Husby and Jennifer Wong for their help in gathering and preparing the data tested in the project, and John Bigham and Swati Pande for their help in data preparation.

REFERENCES

1. Complete Streets - Integrating the Transportation System, DD-64-R1 C.F.R. (2008)
2. City of Portland. (2007). Portland Green Street Program. Retrieved March 23, 2009, from http://www.portlandonline.com/BES/index.cfm?c=44407
3. Richter, E. D., Berman, T., Friedman, L., & Ben-David, G. (2006). Speed, Road Injury, and Public Health. *Annual Review of Public Health, 27*, 125-152.
4. Leaf, W. A., & Preusser, D. F. (1999). Literature Review on Vehicle Travel Speeds and Pedestrian Injuries. Washington, D.C.: National Highway Traffic Safety Administration, United States Department of Transportation.
5. Dumbaugh, E. (2005). Safe Streets, Livable Streets. *Journal of the American Planning Association, 71*(3), 283-298.
6. Dumbaugh, E. (2006). Design of Safe Urban Roadsides: An Empirical Analysis. *Transportation Research Record, 1961*, 62-74.
7. Dulaski, D. M. (2006). *An Evaluation of Traffic Calming Measures and Their Impact on Vehicular Speeds on an Urban Prinicipal Arterial Roadway on the Periphery of an Activity Center*. Paper presented at the ITE Annual Meeting and Exhibit Compendium of Technical Papers.
8. Huang, H. F., & Cynecki, M. J. (2001). The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior. McLean, VA: Turner-Fairbank Highway Research Center, United States Department of Transportation.
9. Knoblauch, R. L., Nitzburg, M., & Seifert, R. F. (2001). *Pedestrian Crosswalk Case Studies: Sacramento, CA; Richmond, VA; Buffalo, NY; Stillwater, MN.*
10. Fitzpatrick, K., Turner, S., Brewer, M., Carlson, P., Ullman, B., Trout, N., et al. (2006). Improving Pedestrian Safety at Unsignalized Crossings. Washington, DC: Transportation Research Board.
11. Ragland, D. R., & Mitman, M. F. (2007). Driver/Pedestrian Understanding and Behavior at Marked and Unmarked Crosswalks: UC Berkeley Traffic Safety Center.
12. Zegeer, C. V., Stewart, R. J., Huang, H. H., Lagerwey, P. A., Feaganes, J., & Campbell, B. J. (2005). Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommendations Guidelines. McLean, VA: Federal Highway Administration.
13. Abdelghany, A. (2005). Above-Ground Actuated Yellow Crosswalk Lights at Uncontrolled Pedestrian Crossings: Alaska Department of Transportation & Public Facilities.
14. Godfrey, D., & Mazzella, T. (2000). Success in Redesigning Main Streets for Pedestrians: City of Kirkland, Washington.
15. Rousseau, G., Miller Tucker, S., & Do, A. (2004). *The Effects on Safety of In-Roadway Warning Lights at Crosswalks: Novelty or Longevity?* Paper presented at the Institute of Transportation Engineers Annual Meeting and Exhibit.
16. Eccles, K. A., Tao, R., & Mangum, B. C. (2004). Evaluation of Pedestrian Countdown Signals in Montgomery County, Maryland.
17. King, M. R. (2000). *Calming New York Intersections.* Paper presented at the Urban Street Symposium.
18. California Bicycle Coalition. (2009). SB 375 (Steinberg), Regional planning for greenhouse gas reduction, travel demand models. *Current Legislation* Retrieved May 5, 2009, from http://www.calbike.org/legislation.htm#SB375

19. California Department of Transportation. (2007). *Caltrans Strategic Plan 2007-2012*. Retrieved April 10, 2009. from http://www.dot.ca.gov/docs/StrategicPlan2007-2012.pdf
20. Assemblyman Mark Leno. (2007). *The Complete Streets Act Fact Sheet*. Retrieved May 23, 2009. from http://www.calbike.org/pdfs/AB1358_Fact_Sheet.pdf.
21. Schneider, R. J., Arnold, L. S., & Ragland, D. R. (2009). Pilot Model for Estimating Pedestrian Intersection Crossing Volumes. *Transportation Research Record*(2140), 13-26.
22. Jacobsen, P. L. (2003). Safety in numbers: more walkers and bicyclists, safer walking and bicycling *Injury Prevention, 9*, 205-209.
23. Raford, N., & Ragland, D. R. (2005). *Pedestrian Volume Modeling for Traffic Safety and Exposure Analysis: The Case of Boston, Massachusetts*. Paper presented at the Transportation Research Board.
24. California Department of Transportation. (2006). *California Strategic Highway Safety Plan Version 2*. Retrieved April 12, 2009. from http://www.dot.ca.gov/hq/traffops/survey/SHSP/SHSP-Booklet-version2_%20PRINT.pdf.
25. Schneider, R. J., Diogenes, M. C., Arnold, L., Attaset, V., Griswold, J., & Ragland, D. R. (2009). *Association between Roadway Intersection Characteristics and Pedestrian Crash Risk in Alameda County, California*. Paper presented at the Transportation Research Board.