THE EFFECTS OF TRANSPORTATION CORRIDORS' ROADSIDE DESIGN FEATURES ON USER BEHAVIOR AND SAFETY, AND THEIR CONTRIBUTIONS TO HEALTH, ENVIRONMENTAL QUALITY, AND COMMUNITY ECONOMIC VITALITY: A LITERATURE REVIEW

UNIVERSITY OF CALIFORNIA TRANSPORTATION CENTER

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INTRODUCTION

This literature review is the culmination of the first phase of a research study directed at reviewing, analyzing, and quantifying the impacts of transportation corridors' design features on user behavior, safety, community and economic vitality, environmental quality, and public health. The research project aims to provide transportation agencies with information to facilitate more defensible measurement of the effects of corridor design features on the quality of life of the communities and rural environments through which they run. The research is directed at transportation corridors under the jurisdiction of state highway departments, and is concerned with controlled-access freeways, expressways, arterials, and "main street" highways. The focus is primarily on corridor roadsides, rather than vehicle roadbeds, because these are the interface zones between roadways and communities or the rural landscape. (See Table 4: Caltrans Terminology for definitions of "roadside" and "roadbed.") Because of their potential contributions to quality of life issues, attention has also been paid to non-roadside design elements that contribute to traffic calming, walkability, and bikability, such as travel lane widths, crosswalks, and bicycle lanes. Funding and time constraints necessarily limit the scope of the research project such that transit-related roadside design elements, such as bus shelters, are not considered.

This literature review assesses the recent published research that has been identified as most relevant for this research project. The ultimate goal of the research project is to develop quantifiable performance measures derived from this review of the research, and then to test the performance measures via case study analysis of selected transportation corridors.

Nationally, departments of transportation are increasing their use of performance measures to assess multimodal transportation systems. However, guidance is generally limited to assessing whether departmental goals are being achieved cost effectively or are generating net benefits, and how those benefits are being distributed. Design features that have less measurable outcomes and benefits are becoming increasingly difficult to justify and prioritize in times of limited

funding. Factors that support quality-of-life and more livable communities have been particularly hard to quantify and measure. Providing quantifiable measures will assist transportation and planning professionals and policy makers in maximizing the potential public benefits associated with investments in state highway right-of-way facilities and associated community networks, systems, and land use environments. The results of this research will enable transportation planners, designers and engineers to understand and communicate the effectiveness and efficiency of corridor design features in enhancing a community's safety, economy and quality of life and health. The results will also be usable by professionals in related fields, such as public health, urban forestry, and real estate.

Although the research should be useful for state highway departments across the United States and like agencies elsewhere, it is particularly directed toward the California Department of Transportation (Caltrans), whose landscape architecture division inspired this research project. Caltrans recognizes that communities across California "expect and demand more context sensitive transportation systems."[1] In order to build transportation systems sensitive to their contexts, however, Caltrans needs defensible measures of the effects of corridor design on non-motorized and motorized safety, physical and psychological health, the environment, and community vitality. Without this information, Caltrans could miss opportunities to serve the communities through which its roadways run, known as its community partners.

California's transportation corridors must meet many needs. They serve multiple travel modes – both motorized (cars, trucks, and transit vehicles) and non-motorized (pedestrians and bicyclists), and local, regional, and interregional traffic. They are the central feature in many urban and suburban neighborhoods and rural communities. In the past, transportation corridors have been designed primarily to maximize the throughput of motorized vehicle traffic. Recently, however,

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[1] Caltrans Research Problem Statement, 2006 – DC-603.
The Caltrans webpage on context sensitive solutions states that the "philosophy for the project development process seeks to provide a degree of mobility to users of the transportation system that is in balance with other values. Caltrans policies, practices, or mandatory design standards provides [sic] a guide for highway designers to exercise sound judgment in applying the policies, practices, or standards consistent with this philosophy. This flexibility is the foundation of highway design and highway designers must strive to provide for the needs of all highway users in balance with the needs of the local community and the context of the project. Caltrans policies, practices or mandatory design standards allows sufficient flexibility in order to encourage independent designs that fit the needs of each situation." http://www.dot.ca.gov/hq/oppd/context/. (Oct. 2, 2008).

members of local communities have begun to question the wisdom of this approach, and have sought to design corridors that also meet local needs and better accommodate multiple travel modes. Such efforts are supported by an increasing focus among city planners, designers, transportation engineers, and public health practitioners on enhancing the quality of life within communities. This quality of life is affected by high volumes of motorized traffic that move faster than pedestrians and thus diminish traffic safety; increasing levels of obesity that may be related to community design qualities and reduced levels of physical activity; increases in air and water pollution levels due to automobile and truck throughput; and a growing population of baby boomers who may lose their mobility if options other than driving alone are not provided.

A transportation corridor communicates many things to its users through its design elements. What it communicates can affect the travel mode a user decides to take, the speed at which a motorist decides to drive, whether a pedestrian will walk along or across a street, and whether a resident will bicycle to local shops. Design elements give visual cues to the users of transportation corridors that let them know where they are and how to behave. The vehicle lane widths, presence or absence of sidewalks, and presence or absence of buffering elements such as street trees and parked cars all influence a user's perceptions and resulting behavior responses. Is it safe and pleasant to walk here? Can I safely cross the street? Can I drive fast here, or should I slow down?

Although a main focus of the State Highway System is to meet state and regional goals of moving vehicular traffic at a high level of service (LOS), over time it has become apparent that the existing roadway designs and standards often conflict and miss opportunities to partner with local communities to meet local, regional, and state needs and goals. Within the planning and transportation fields, research on the safety impacts of street design elements, such as narrower vehicle lane widths, parked cars, street trees, bicycle lanes, and wider sidewalks has been conducted, and models of ideal "main streets" have been developed. However, no comprehensive defensible performance measures exist for assessing the safety, health, economic, and quality of life effects of corridor design elements. This research project aims to provide such measures.

Project Methodology

Research Project Outline

The research project is scheduled to have three phases: a literature review, development of performance measures, and a field study to test the performance measures. The first phase is now complete; this report presents the findings from the literature review.

The literature review includes research coming from multiple academic fields, particularly transportation planning, urban planning, urban design, and environmental science. In addition to synthesizing the research findings, gaps in the research have been identified and directions for further research have been directed. A draft version of this literature review was circulated to a Technical Advisory Group, composed of leading professional and academic experts in the field, who contributed their understanding of the issues, needs, and opportunities associated with transportation corridor design.

The Technical Advisory Group will also lend their expertise to the second phase of the study, which will involve the development of performance measures and a cost/benefit framework for highway corridor design that can be used by Caltrans and other transportation planning professionals to account for community values as well as formal transportation goals when planning, designing, or evaluating highway projects.

The third phase of the research project will involve the identification of one or more Caltrans corridors to be studied using the performance measures. Initial roadway types for study are urban arterials, limited access freeways, and rural highways. This part of the research will investigate how individual design features and the shaping of whole environments can influence and result in specific behaviors and benefits.

Literature Review Methodology

The research team began the literature review by casting a wide net to find and examine studies dealing with the effects of transportation corridors' features on user safety; walkability, bikability, and physical health; psychological well-being; community and economic vitality; and varying environmental concerns. Approximately 180 studies and reports were reviewed, including articles published in leading industry journals, studies conducted by various university research centers, dissertation studies, and research undertaken by government agencies at all levels.[2]

Because of the need to put some boundaries around an already extensive research focus, not all research covering quality of life concerns that may have some relevance for corridor roadside design has been covered. When selecting what areas of research concern to cover, it was decided to focus on research directly related to the physical, designable corridor features. Broader areas of research concern, such as investigations of the benefits of reducing vehicle-miles traveled (VMT), are not covered by this review. In addition, rather than presuming to create a comprehensive review of every piece of applicable research, the researchers sought to include the most recent and relevant research. While they undertook an extensive search of research databases and academic journals, inevitably some important research will have been missed, though hopefully not much.

The research covered in this literature review underscores the conflicting goals of the transportation profession: 1) vehicular mobility as measured by speed and throughput, and 2) safety and environmental stewardship. The research efforts and their findings reveal that not only does an increase in speed generally contribute to a less safe environment for all roadway users, it has been prioritized such that safety treatments applied elsewhere in the world – street and travel lane narrowing, landscaping with trees, and certain types of traffic calming – are viewed much more critically in the United States, and at times are completely prohibited. Trees, in particular, have been identified as hazards to unsafe drivers who may be intoxicated, inattentive, or exceeding the speed limit, and therefore proscribed in some areas where they

[2] For a list of all literature reviewed, see the bibliography.

might be of great benefit for environmental and other reasons, and would likely be much less hazardous with lower design speeds.

In place of speed-lowering measures, United States' engineering practice relies heavily on the concept of "passive safety" to protect users. Passive safety assumes that humans are bound to make mistakes, and that roadways ought to therefore be forgiving. As such, extra space is built into the roadway to provide a safety net in case a driver loses control and runs off the road or temporarily exits his lane. One result of this concept has been the "clear zone", an approximately 30-foot clear space on the sides of controlled access highways from which immobile objects, such as mature trees with trunks greater than 4 inches, are restricted.[3] While in theory this may sound like a good idea, research has been inconclusive that the strategies have increased driver safety by significant measures. In contrast, several studies, many of which are highlighted in this review, have shown that wider lanes encourage faster speeds due to a concept known as "environmental reference." These studies have also been quite conclusive about the detrimental effects of increased vehicle speeds on pedestrians and bicyclists.

What follows is an attempt to tie together Caltrans' stated mandates, goals, and policies with relevant research findings that point to new ways of designing roadways, so that communities can benefit from a more holistic strategy of transportation planning and design in the future. Chapter I reviews Caltrans policies that are pertinent to this research project, particularly those policies relevant to quality of life and livable community concerns. It discusses how Caltrans defines the different highway types under its jurisdiction, and reviews Caltrans policies related to Context Sensitive Solutions (CSS), including recent national and state level plans and legislation that support these policy approaches. Chapters II through V, which comprise the bulk of this report, summarize and synthesize the relevant research and literature according to subject matter. Chapter II is concerned with the safety effects of highway design. It is divided into three sections: driver safety, pedestrian safety, and bicyclist safety. It focuses on the recent body of research that either questions long held assumptions about what makes a highway safe for drivers, or addresses issues of multi-modal safety. Chapter III is concerned with the relationship between highway design and community and individual health effects, both physical and

[3] More detailed information about highways can be found in Table 4.

psychological. Incorporated into this chapter are sections that review the literature on walkability and bikability, as these characteristics seem to influence community health, and whether or not a community is considered walkable or bikable is strongly related to how its streets are designed.

Chapter IV deals with the effects that highway roadway and roadside design has on a community's economic vitality. To a large extent, the research is concerned with the effect of roadside trees, landscaping, and other pedestrian improvements on community vitality as measured by property values and preferences. Chapter V is concerned with how highway design might contribute to mitigating the negative environmental impacts that typically come with urbanization. For the most part, it summarizes research that has investigated the actual and potential effects of urban trees, particularly street trees. The final chapter draws conclusions from the literature review and identifies next steps.

CHAPTER I: CALTRANS POLICIES AND CONTEXT SENSITIVE SOLUTIONS

Context Sensitive Solutions

California is considered forward thinking in many ways, and transportation planning is no exception. The state has more "Bicycle Friendly" communities, as awarded by the League of American Bicyclists, than any other state, and until recently, Davis, California, was the only city given the League's platinum rating. (Portland, Oregon; and Boulder, Colorado, recently received platinum rating as well.) California also pioneered bicycle boulevards and traffic calming measures that block streets for cars, but allow bicyclists and pedestrians, as seen in Berkeley.[4] As part of its planning process, Caltrans aims to design using principles of "Context Sensitive Solutions" (CSS). The Federal Highway Administration, which formalized the concept of CSS, describes it in this manner:

> Context sensitive solutions (CSS) is a collaborative, interdisciplinary approach that involves all stakeholders to develop a transportation facility that fits its physical setting and preserves scenic, aesthetic, historic and environmental resources, while maintaining safety and mobility. CSS is an approach that considers the total context within which a transportation improvement project will exist.[5]

Caltrans has elaborated on the policy and tailored it to be California-specific. Following is language from the Caltrans Context Sensitive Solutions webpage:

> Quality transportation design is the culmination of philosophy and principles in the project development process that provides a transportation system that enhances the place in which it serves. Whether a project is in an urban, rural or natural setting, the transportation facility must be in harmony with the community goals and the natural environment. The purpose of [Caltrans' Context Sensitive Solutions] website is to provide Caltrans designers and its partners with department policy, guidance and examples to ensure the protection and enhancement of the environment and quality of life while meeting the multi-modal transportation needs in California.[6]

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[4] City of Berkeley. Traffic Calming in Berkeley. http://www.ci.berkeley.ca.us/transportation/trafficcalming/TCinBerkeley.html (April 29, 2008).
City of Berkeley. Bicycle Boulevards in Berkeley. http://www.ci.berkeley.ca.us/transportation/Bicycling/BB/BicycleBoulevard.html (April 29, 2008).
[5] Federal Highway Administration. Context Sensitive Solutions. http://www.contextsensitivesolutions.org/content/topics/what_is_css/. (May 1, 2008).
[6] Caltrans. Context Sensitive Solutions. Emphasis added. http://www.dot.ca.gov/hq/oppd/context/. (Jan. 20, 2008).

Supporting Caltrans Policies

To encourage the use of CSS to design roadway corridors, Caltrans has developed several other policies whose goals align with CSS. Many of these policies are specifically geared toward pedestrians and bicyclists, whether to protect their safety or to encourage more trips by these modes. The key USDOT and Caltrans policies are excerpted in Table 1 below. (Policies related to public transit also exist, but these are not included here because transit related elements are not a part of this study.)

Table 1. Selected Policies and Laws Encouraging Safety and Non-Motorized Travel

Caltrans Statement of Mission and Goals[7]	1. **Safety** – provide the safest transportation system in the nation for users and workers. 2. **Mobility** – Maximize transportation system performance and accessibility. 3. **Delivery** – Efficiently deliver quality transportation projects and services. 4. **Stewardship** – Preserve and enhance California's resources and assets. 5. **Service** – Promote quality service through an excellent workforce.
Caltrans Deputy Directive 64: Accommodating Non-Motorized Travel[8]	"The Department **fully considers the needs of non-motorized travelers** (including pedestrians, bicyclists and persons with disabilities) in all programming, planning, maintenance, construction, operations and project development activities and products. This includes **incorporation of the best available standards** in all of the Department's practices…Attention must be given to many issues including…**safe and efficient transportation** for all users of the transportation system, **provision of alternatives** for non-motorized travel…**elimination or minimization of adverse effects** in the environment, natural resources, public services, aesthetic features and the community…"
California Blueprint for Walking and Bicycling[9]	Established statewide goals of: • A **50 percent increase in the number of bicycling and walking trips by the year 2010** (compared to base year 2000 levels) • A **50 percent decrease in the bicycle and pedestrian fatality rates by the year 2010** (compared to base year 2000 levels) • Increased funding for bicycle and pedestrian programs as necessary to meet these goals

[7] Caltrans. Mission and Goals. http://dot.ca.gov/hq/paffairs/about/mission.htm. (Jan. 20, 2008). Emphasis added.
[8] Caltrans. Deputy Directive 64: Accommodating Non-Motorized Travel. March 2001. Emphasis added.
[9] Caltrans. California Blueprint for Walking and Bicycling. May 2002. Emphasis added. www.dot.ca.gov/hq/tpp/offices/bike/sites_files/CABlueprintRpt.pdf. (Oct. 2, 2008).

USDOT TEA-21 Legislation[10]	"**Bicyclists and pedestrians shall be given due consideration in the comprehensive transportation plans** developed by each metropolitan planning organization and State."
Accommodating Bicycle and Pedestrian Travel: A Recommended Approach (a US DOT policy statement on Integrating Bicycling and Walking into Transportation Infrastructure)[11]	1. Bicycle and pedestrian ways shall be established in new construction and reconstruction projects in all urbanized areas unless bicyclists and pedestrians are prohibited by law from using the roadway, the cost of establishing bikeways or walkways would be excessively disproportionate to the need or probable use, or sparsity of population or other factors indicate an absence of need. 2. In rural areas, paved shoulders should be included in all new construction and reconstruction projects on roadways used by more than 1,000 vehicles per day, as in States such as Wisconsin. 3. Sidewalks, shared use paths, street crossings (including over- and under crossings), pedestrian signals, signs, street furniture, transit stops and facilities, and all connecting pathways shall be designed, constructed, operated and maintained so that all pedestrians, including people with disabilities, can travel safely and independently. 4. The design and development of the transportation infrastructure shall improve conditions for bicycling and walking through…planning for the long-term,…addressing the need for bicyclists and pedestrians to cross corridors as well as travel along them,…designing facilities to the best currently available standards and guidelines.
FHWA Guidance: Mainstreaming Non-Motorized Transportation[12]	"Even where circumstances are exceptional and bicycle use and walking are either prohibited or made incompatible, States, MPOs, and local governments must still ensure that bicycle and pedestrian access along the corridor served by the new or improved facility is not made more difficult or impossible."
California Transportation Plan 2030[13]	"A major focus of SAFETEA-LU and of the CTP 2030 Addendum (the update to California's 2025 Transportation Plan) is the **linking of transportation planning with natural resource and environmental planning** to promote early consultation. … **The goal of this early consultation is transportation plans, and ultimately projects, that preserve and enhance California's valuable natural and environmental resources**."
California Transportation Plan 2030[14]	"The CTP's vision is one of a fully integrated, multimodal, sustainable transportation system that supports the three outcomes (3Es) that define quality of life – **prosperous economy, quality environment, and social equity**."

[10] U.S. Congress. 1998. Transportation Equity Act-21. Title 23, § 217:1202 (a). Washington, DC. Emphasis added.
[11] USDOT. http://www.fhwa.dot.gov/environment/bikeped/design.htm. (Oct. 2, 2008).
[12] FHWA Guidance, Policy: Mainstreaming Nonmotorized Transportation. February 1999.
[13] Caltrans. California Transportation Plan 2030. http://dot.ca.gov/hq/tpp/offices/osp/ctp.html. Emphasis added. (Jan. 20, 2008).
[14] Caltrans. California Transportation plan Fact Sheet. http://www.ice.ucdavis.edu/CTP/Consultation%20Meeting/CTP_SAFETEA-LU_FactSheet_Pub_Meetings5.pdf. Emphasis added. (Jan. 20, 2008).

It should be noted that although Caltrans values working with its partner communities, the goals of the two do not always easily align. There are times, for example, when Caltrans may want to install a sidewalk along a neighborhood street and is opposed by local property owners who do not want to give up part of their property for such a community use. It is hoped that in this situation, the transportation planners and engineers would be able to use CSS to find a compromise between the community members and Caltrans in order that broader goals may be achieved.

Traffic Safety in California

While the policies represent a step toward a stronger consideration of local community needs, particularly in relation to cycling and walking, traffic safety and transportation facts from California indicate that they could be enhanced. Table 2 shows California's standing with regard to pedestrian traffic safety in comparison to the overall United States, as well as New York and Oregon – two states known for having a relatively high number of pedestrians and bicyclists. These statistics suggest that pedestrian safety needs to be further improved.

Table 2. Traffic Safety and Pedestrian Travel in California and Comparable Areas

Source	US	CA	NY	OR
% Walk for Commute Purposes (2000)[15]	2.93	2.85	6.23	3.57
Pedestrian deaths as % of Total (2006)[16]	11	16.9	21.4	9.9
Pedestrian Fatalities per 100,000 population (2006)	1.6	1.97	1.62	1.27

As the numbers illustrate, California has higher rates of pedestrian fatalities than the national average, even though it has a lower mode share for walking than the national average. Although New York has a higher percentage of pedestrian deaths, it also has twice as many pedestrian trips, suggesting that it may actually be safer when exposure is controlled for. Oregon, on the other hand, has a higher number of trips and a lower fatality percentage. Clearly, California could improve its pedestrian safety record.

[15] U.S. Census data for Walking. 2000. P30 Means of Transportation to Work for Workers 16 Years and Over. http://factfinder.census.gov (April 24, 2008).
[16] National Highway Traffic Safety Association. Traffic Safety Facts – 2006 Data for Pedestrians.
[18] U.S. Census data for Bicycling. 2000. P30 Means of Transportation to Work for Workers 16 Years and Over.

Table 3. Traffic Safety and Bicycle Travel in California and Comparable Areas

Source	US	CA	NY	OR
% Bicycle for Commute Purposes (2000)[18]	0.38	0.83	0.3	1.07
Pedalcycling deaths as % of Total (2006)[19]	1.8	3.3	3.1	2.9
Pedalcycling Fatalities per 1,000,000 population (2006)	2.58	3.87	2.33	3.78

The numbers for bicycling illustrate that California has both a higher mode share of bicycling and a higher rate of bicycling fatalities than the national average. In comparison with New York, California is clearly doing better, although Oregon still seems to have provided safer and more well-used facilities. This indicates that, although California is above average, there is room for improvement in terms of providing safety for and encouraging the population of cyclists.

Caltrans Terminology

The audience for this report is mixed: it is addressed to Caltrans personnel as well as to academic researchers and professional practitioners. In the analysis of research findings contained in this report, an attempt has been made to use Caltrans terminology as much as possible. As such, researchers and design professionals will want to be aware of Caltrans definitions of terms. Table 4 lists Caltrans definitions of roadways types and roadway elements.[20] It should be noted that for Caltrans, the term "highway" encompasses both freeways, which have limited-access, and conventional highways, to which access is not restricted. Again, we stress that the thrust of this report has to do primarily with roadside design elements.

Table 4. Caltrans Terminology

Highway Types	
Highway	(a) Arterial Highway—A general term denoting a highway primarily for through traffic usually on a continuous route. (b) Bypass—An arterial highway that permits traffic to avoid part or all of an urban area.

[19] National Highway Traffic Safety Association. Traffic Safety Facts – 2006 Data for Bicycling. NHTSA combines bicycles, unicycles and tricycles in the same category and refers to them collectively as "pedalcycles."
[20] Caltrans. Highway Design Manual. Chapter 60 Nomenclature.

	(c) Divided Highway—A highway with separated roadbeds for traffic in opposing directions. (d) Major Street or Major Highway—An arterial highway with intersections at grade and direct access to abutting property and on which geometric design and traffic control measures are used to expedite the safe movement of through traffic.
Freeway	A freeway, as defined by statute, is a divided arterial highway with full control of access and with grade separations at intersections. The owners of abutting lands have limited or restricted, if any, rights or easement of access to or from their abutting lands.
Controlled/Limited Access Highway	In situations where it has been determined advisable by the Director or the CTC, a facility may be designated a "controlled access highway" in lieu of the designation "freeway". All statutory provisions pertaining to freeways and expressways apply to controlled access highways.
Expressway	An arterial highway with at least partial control of access, which may or may not be divided or have grade separations at intersections. The owners of abutting lands have limited or restricted, if any, rights or easement of access to or from their abutting lands.
Conventional Highway	A highway without control of access which may or may not be divided. Grade separations at intersections or access control may be used when justified at spot locations.

Geometric Cross Section	
Multiple Lane	Freeways and conventional highways are sometimes defined by the number of through automobile traffic lanes in both directions. Thus an 8-lane freeway has 4 through automobile traffic lanes in each direction. Likewise, a 4-lane conventional highway has 2 through automobile traffic lanes in each direction.
Median Lane	A speed change lane within the median to accommodate left turning motor vehicles.
Traffic Lane	The portion of the traveled way for the movement of a single line of motor vehicles.

Median	The portion of a divided highway separating the traveled ways for traffic in opposite directions.
Roadbed	That portion of the roadway extending from curb line to curb line or shoulder line to shoulder line. Divided highways are considered to have two roadbeds.

Roadside	**A general term denoting the area adjoining the outer edge of the roadbed to the right of way line. Extensive areas between the roadbeds of a divided highway may also be considered roadside.**
Roadway	That portion of the highway included between the outside lines of the sidewalks, or curbs and gutters, or side ditches including also the appertaining structures, and all slopes, ditches, channels, waterways, and other features necessary for proper drainage and protection.
Shoulder	The portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles and for emergency use.
Traveled Way	The portion of the roadway for the movement of vehicles, exclusive of shoulders.

Traffic	
Annual Average Daily Traffic	The average 24-hour volume, being the total number during a stated period divided by the number of days in that period. Unless otherwise stated, the period is a year. The term is commonly abbreviated as ADT or AADT.
Level of Service	A rating using qualitative measures that characterize operational conditions within a traffic stream and their perception by motorists and passengers. The term is commonly abbreviated as LOS.
Design Speed	A speed selected to establish specific minimum geometric design elements for a particular section of highway.

CHAPTER II: SAFETY EFFECTS OF CORRIDOR ROADSIDE DESIGN ELEMENTS

One of the biggest challenges for highway design has long been the conflict between what is considered safe and what is considered aesthetically pleasing. As many of the studies that are discussed in Chapters III and IV of this report document, people tend to have a strong preference for roadside greenery and the presence of roadside trees seems to be associated with greater levels of both human comfort and community walkability, and hence may contribute to increased levels of physical activity and psychological well-being. At the same time, some transportation research has connected the presence of roadside trees with an increased chance of crashes and increased accident severity. Erring on the side of caution, and in agreement with the national AASHTO guidelines, the Caltrans Highway Design Manual specifies that a clear zone of a desirable 40 feet, but minimum 30 feet, must be maintained alongside limited access highways.[21] Conventional highways such as arterials must maintain a 20-foot wide roadside clear zone where speed limits are above 40 mph; for conventional highways with a speed limit of 40 mph or less, clear zone widths do not apply if there is a curb present. Where it is required, the clear zone must be free of any immobile object, including trees with trunks greater than 4 inches in diameter.

Another related challenge for highway design, which has grown in importance in recent years because of the climate change crisis, is the conflict between what is considered safe and what is environmentally responsible. Research coming from a variety of academic fields, discussed in Chapter V of this report, indicates that urban trees contribute a host of environmental benefits, and that street trees may be particularly important.

A third challenge of not small significance is how to achieve safety for non-motorized travel as well as safety for drivers, particularly in situations where multiple travel modes normally exist, such as on urban arterials.

[21] Caltrans. Highway Design Manual. Chapter 300 – Geometric Cross Section.

The need for highway design to strike a balance between safety concerns, aesthetic concerns, and environmental concerns has been recognized, and is codified in places. For example, Chapter 900 of the Highway Design Manual recognizes the benefits of vegetation for "aesthetic, safety, environmental mitigation, storm water pollution prevention, (and) erosion control purposes", as well as "headlight glare reduction, fire retardance, windbreak protection, or graffiti reduction on retaining walls…"[22] It specifies several guidelines for maintaining a balance between "aesthetics, safety, maintainability, cost-effectiveness, and resource conservation", and suggests that "plantings should be responsive to local community goals." Even with this mandate however, clear zones along highways are strictly enforced.

Increasingly, communities want highways that are more context sensitive, particularly those urban and suburban arterials that function as main streets in the communities through which they pass. In conjunction with the growing concern that public infrastructure can and should contribute to greater environmental sustainability, recent transportation research is revisiting the assumption that roadside trees must be eliminated for safety reasons. Using spatial Geographic Information Systems (GIS) data and analysis, this research is probing a variety of questions. One research focus, directed at understanding how driver behavior is influenced by highway roadside design, explores the relationships between driver speed, posted speed limit, and the presence or absence of roadside design elements like guardrails and trees, which may contribute an "environmental reference" for reinforcing the speed limit. Other researchers have investigated the association between various highway roadside design elements and the frequency and severity of run-off-roadway accidents. This research seeks to identify specific highway design features, such as medians or shoulders, or the presence or absence of trees, which are positively or negatively correlated with collision rates.

Some of these research efforts cast a wide net for associations and use regression models incorporating a number of variables. These studies illuminate aspects of the safety question, but the most robust results tend to be fairly general, with more specific results acknowledged as potentially confounded. Other efforts focus solely on the safety impacts of roadside trees and generally do a better job of controlling for variables, leading to stronger conclusions.

[22] Caltrans. Highway Design Manual. Chapter 900 – Landscape Architecture.

Along with the studies focused on driver safety related to highway design, many researchers are investigating the impacts of highway roadside design on pedestrian safety, and some are looking at the impacts on bicycle safety. Some of this research focuses on the effects of traffic calming in general, while other studies focus on the safety effects of specific traffic calming measures, including those of particular pedestrian crossing treatments. Much of this research involves empirical case study analysis and surveys, while other studies use computer simulations and/or advanced modeling techniques.

What follows in this chapter is a compilation and synthesis of the recent research that has explored the safety effects of various highway design configurations and roadside landscaping elements. The analysis is divided into three sections: driver safety, pedestrian safety, and bicyclist safety. In each section, the research discussed applies to a variety of roadway types, with an emphasis on conventional highways such as urban/suburban arterials, arterial "main streets," and rural highways.

Driver Safety

Research that has investigated the impact of roadside design elements on driver safety can be grouped into two main categories of concern: how driver speed is affected by highway roadside design elements (environmental reference), and whether or not roadside trees contribute to the severity of run-off-roadway accidents.

Driver Speed and Highway Roadside Design Elements (Environmental Reference)

Higher highway driving speeds are associated with more driving collisions and a higher rate of fatalities. As such, it is important to understand what impacts roadside design elements might have on driver's perceptions of highway safety and on driving speed.

That highway driving speeds are associated with more vehicle crashes and greater crash fatalities is well documented. **Richter et al. (2006)** examined the relationship between highway driving

speeds and vehicle crashes in various countries.[23] They found that while countries such as England, France and Australia have in recent decades reduced highway speed limits and aggressively enforced those limits in order to improve roadway safety, the United States has raised highway speed limits *and* been slow to adopt speed limit enforcement techniques. While the former countries have seen resultant gains in highway safety, the United States has experienced marked decreases in safety. In the 1970s, in response to an energy crisis, the United States imposed a nationwide 55-mph highway speed limit. This move resulted in a reduction of over 9,000 highway fatalities during the first year of its implementation, and from 2,000 to 5,000 fewer in subsequent years. After the nationwide speed limit was lifted in 1995, however, the number of interstate highway fatalities reported in many states increased by an average of 17%. By 2003, when most states had raised the speed limit to 70 mph or higher on at least some of their highways, the number of highway fatalities increased by over 35% in those states. These trends strongly imply that higher vehicle travel speeds are associated with more frequent and more severe crashes.

A number of European countries design highways around the concept of "environmental reference speed." During a 2001 field study of European best roadway design practices, **Brewer et al. (2001)** learned that the countries they visited (Denmark, Sweden, The Netherlands, and England) all used a type of environmental reference speed, even though each defined "design speed" differently.[24] The environmental reference speed was implemented via the use of physical design elements meant to reinforce the desired speed, such as speed humps and striping that visually narrows the roadway. As well, where a <u>highway</u> served as a <u>principal urban or suburban street</u>, each country tended to sacrifice vehicle speed for safety gains. Although Caltrans considers traffic safety to be among its top priorities, further examination of selected European practices could shed light on how to better achieve traffic safety goals for all users.

Numerous research studies support the idea that physical elements along highway roadsides, such as parking lanes, trees, and closely-spaced buildings, can serve as environmental references

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[23] **Richter, Elihu D.**, Tamar Berman, Lee Friedman, and Gerald Ben-David. 2006. Speed, Road Injury, and Public Health. *Annual Review of Public Health* 27:125-52.

[24] **Brewer, Jim**, John German, Ray Krammes, Kam Movassaghi, John Okamoto, Sandra Otto, Wendell Ruff, Seppo Sillan, Nikiforos Stamatiadis, and Robert Walters. 2001. Geometric Design Practices for European Roads. Federal Highway Administration.

that reinforce lower design speeds and are therefore important mechanisms for influencing drivers to travel at a desired speed. **Dumbaugh (2005)** examined this concept in his study of an arterial highway in Orlando, Florida.[25] Comparing two approximately 1-mile segments of an arterial highway having the same right-of-way width but different cross-sectional configurations, he found that the section that had been designed to be "livable" was safer in every respect than the comparison section (see Table 5 for the design characteristics). During a five-year evaluation period, the livable section had fewer vehicular collisions of every kind and far fewer pedestrian and bicyclist injuries and fatalities. While six mid-block fatalities occurred on the comparison section, including three that involved pedestrians, none occurred on the livable section.

Table 5. Characteristics of Livable vs. Comparison Street Sections

Travel Lanes	Other	Sidewalks	Street Trees	Building Setback	Speed Limit
11 feet	6.5-foot parking lane	Y	Y	Negligible	40 mph
12.5 feet	20-foot shoulder	N	N	Wide	45 mph

Based on his findings and the results of several previous studies that had investigated roadway design, speed, and driver behavior, Dumbaugh theorized that humans operate using *risk homeostasis*, or a subconscious gauging of risk to guide behavior. On roads where safety is built-in via wide traffic lanes or shoulders, the brain subconsciously interprets the greater amount of space as permission to be less careful; the result is generally less caution when driving. In contrast, on a roadway where low speed is communicated through design, drivers tend to be more alert and careful because there is less room for error. This *risk homeostasis* may therefore negate the purported safety gains of passive design, as the brain takes advantage of the greater leeway to be less careful. In contrast, designs that force drivers to pay attention and slow down may improve overall safety for users on the roadway.

Exploring roadside environmental references as a device for lowering driving speeds is important because research suggests that posted speed limits alone do not always have the desired impact. **Mannering (2008)** recently published a study on the effects of posted speed limits on driver

[25] **Dumbaugh, Eric**. 2005. Safe Streets, Livable Streets. *Journal of the American Planning Association* 71(3):283-298.

speed.[26] His analysis found that drivers associate the safety of certain speeds with the speed at which they believe they will receive a citation rather than with the posted speed limit. He also found that drivers who had been stopped for speeding in the year prior to the analysis were more likely to believe that safety was not compromised until approximately 20 mph over the speed limit. Clearly, these findings suggest that law enforcement is necessary to achieve desired highway speeds. However, given that enforcement is a limited resource, the findings also suggest that roadways should be designed to communicate preferred speeds via their design.

While some research has shown that the posted speed limit can have a major influence on driver speeds, the most thorough studies indicate that environmental reference is also important. It seems that both traffic lane width and roadside design have impacts. While traffic lane width is not a direct concern of this research, a brief consideration of the subject matter is included here because it affects considerations of overall roadway safety, and roadside design is impacted by the distribution of total right-of-way space between the roadbed and the roadsides.

Fitzpatrick et al. (2000) conducted a study of 55 four-lane arterial street segments (19 curved; 36 straight) in Texas in order to investigate what elements of the roadways affected driver speed.[27] The posted speed limit, which ranged from 30-45 mph, was found to be the most significant variable for both straight and curved street segments. However, for the curved segments, deflection angle and access density (i.e. the frequency of highway access points) were also significant, and for the straight segments lane width was significant when controlling for the posted speed limit. On the straight sections, 10-foot lanes carried an 85th percentile speed 9.4 mph slower than 13-foot lanes.

A study by **Potts et al. (2007)** used a database containing comprehensive information about site characteristics, traffic volumes, and collisions on highways in Minnesota and Michigan to

[26] **Mannering, Fred**. 2008. Speed limits and safety: A statistical analysis of driver perceptions. Transportation Research Board.
[27] **Fitzpatrick, Kay**, Paul Carlson, Marcus Brewer, and Mark Wooldridge. 2000. Design Factors That Affect Driver Speed on Suburban Streets. *Transportation Research Record* 1751:18-25.

investigate the relationship between lane widths and safety on urban and suburban arterials.[28] The researchers looked at the following roadway geometries: two-lane undivided arterials, three-lane arterials with a center turn lane, four-lane undivided and divided arterials, and five-lane arterials with a center turn lane. Lane widths on the highways ranged from 9 to 13+ feet. The research found no general indication that mid-block lanes narrower than 12 feet contributed to increased crash frequencies, except in the cases of undivided four-lane arterials with lane widths of 10 feet or less and divided four-lane arterials with lane widths of 9 feet or less. Evaluation of the intersection approaches showed no significant indication that narrower lanes increased crash frequencies. Approaches to four-way stop-controlled arterial intersections with lane widths of 10 feet or less were associated with higher crash frequencies in one state, but lower crash frequencies in the other. The researchers did not suggest explanations for these findings.

Overall, these findings imply that lane widths narrower than 12 feet can be used in many cases – a particularly important finding for urban areas, where pedestrians cross streets frequently, and where wider roadbeds can make crossings more difficult. These findings suggest that a strategy of reducing travel lane widths to enhance pedestrian safety can be accomplished without negatively affecting driver safety, a strategy routinely used in European countries. Further research regarding the impacts of narrower lane widths on driver speed and overall traffic safety is needed.

Returning to the impacts of roadside design on driver speed, **Van der Horst and Ridder (2007)** conducted a controlled laboratory experiment with a driving simulator to investigate the influence of roadside infrastructure on driver speed and vehicle positioning for both curved and straight highways.[29] Twenty experienced drivers completed 24 randomly ordered, simulated drives along multilane highways that differed with regard to whether they were curved or straight, whether or not they had shoulder lanes, roadside guardrail barriers (of various types,

[28] **Potts, Ingrid B.**, John F. Ringert, Douglas W. Harwood and Karin M. Bauer. 2007. Operational and Safety Effects of Right-Turn Deceleration Lanes on Urban and Suburban Arterials. *Transportation Research Record*: No 2023.

[29] **Van der Horst, Richard** and Selma de Ridder. 2007. The Influence of Roadside Infrastructure on Driving Behavior: A Driving Simulator Study. Transportation Research Board.

color, and heights), and roadside trees, and how close to the roadway the trees were located. The key findings regarding the interaction between the variables are listed in Table 6.

Table 6. Results from the Driving Simulation According to Roadway Characteristics

Type	Guardrail	Shoulder	Trees	Result
Straight	Y	N	N	Driver speed slowed just before guardrail, but did not remain lower while traveling along the guardrail. Lateral positioning significantly farther away from the right lane marking.
Straight	Y	Y	N	With the shoulder, the guardrail seemed to have little effect on speed.
Straight	N	Y	N	Lateral positioning significantly farther away from the right lane marking.
Curved	Y	N/A	N/A	When the guardrails were painted a standard gray, driver speed was significantly faster than when the guardrails were painted with black-and-white stripes. For both types, drivers significantly increased their speeds and positioned vehicles closer to roadway right-edge upon completion of the curve.
Straight, Curved	N/A	N/A	14.76 feet from roadway edge	Little effect on driver speed, but a marked effect on lateral vehicle position.
Straight, Curved	N/A	N/A	6.6 feet from roadway edge	Significant slowing of driver speed, with or without guardrails. Greatest when driver first encountered the trees, lessening over time. Marked effect on lateral vehicle position: 0.15-0.35 feet further away from the edge than on average.

These findings seem to corroborate the idea of environmental reference – the drivers slowed their driving speeds upon encountering the trees closer to the roadway, suggesting that they "read" the surroundings and reacted accordingly.

Research by **Steyvers and DeWaard (2000)** compared driver speeds on low-speed (20 mph) rural highways in the Netherlands that had different edge delineation characteristics.[30] In one study, they used video cameras to capture and compare driving speeds on two edge-lined

[30] **Steyvers, F.J.J.M.** and D. DeWaard. 2000. Road-edge Delineation in Rural Areas: Effects on Driving Behavior. *Ergonomics* 43 (2):223-238.

highways, one with a continuous painted edge line and one with a dashed edge line, and on two control roadways without edge lines, one with a dashed center axis line and one without any lines. They found that drivers on edge-lined highways drove more closely to the center of the road than those on the axis-lined highway, especially when it was dark. Driving speeds were highest on the axis-lined highway, next highest on the edge-lined highways, and lowest on the unlined highway.

A second controlled experiment designed to elicit driver preferences for different highway edge conditions used a driving simulator to test driver speeds on simulated drives through the same highway segments. It also measured participants' physical bodily responses while taking the simulated drives, and gave them a post-experiment survey. Analysis of the resulting data revealed that although the drivers generally preferred unlined roadways the least, drivers' mental ability and heart rate did not vary based on the different highway edge conditions. In other words, lack of roadway striping does not seem to contribute to driver stress. Based on the combined findings of the two studies, the researchers concluded that visual guidance increased driving speeds, and that edge lines enabled better steering in spite of the increased speeds.

Interpreting these findings for highway roadside design is complex. The findings suggest that painted roadside edge lines may contribute to increased traffic safety via enabling better driver steering, while at the same time contributing to decreased traffic safety by encouraging faster driver speeds. In addition, since the research looked only at very low speed highways, it is not known if the findings hold true for higher speed highways. Future research that looks at the use of unlined highways with higher travel speeds could provide more guidance as to whether or not this strategy would be effective for slowing driver speeds on the majority of rural roadways.

Overall, the research reviewed above points to the importance of roadway design in communicating the preferred highway speed to drivers; i.e., such communication should not be left up to speed limit postings alone, but should be reinforced via design characteristics, including those of the roadside. The research findings suggest that the practice of roadway design should be encouraged to include the possibilities of narrowing a roadway, changing the geometry, or including roadside features such as trees and guardrails to encourage slower speeds

where desired. The research and findings presented here spur many roadway design strategies that should be explored for their impact on driver speed and safety.

Run-off-roadway Collisions and the Debate about Trees as a Safety Hazard

Many researchers have sought to understand the relationship between various roadside elements and the frequency and severity of run-off-roadway vehicle crashes. Some of this research has focused on the effects attributable to the presence or absence of a raised central median separating opposing traffic flows, and whether or not trees on the median make a difference. Other research has focused on the effects attributable to right-side roadway elements, such as the presence of a wide or narrow shoulder, with or without trees. Of concern is that some of the research does not effectively address crash causation or adequately theorize crash attribution: i.e., when driver fatigue, speeding or alcohol use is involved in a crash with a tree, is it appropriate to attribute the crash or its severity to a tree effect instead of a behavior effect, leading to recommendations for tree removal rather than improved behavior control?

Nueman et al. (1999) looked at studies and surveys about run-off-roadway collisions conducted by fourteen state Departments of Transportation.[31] The researchers found that 8% of all fatal accidents in 1999 involved trees, and that 90% of those accidents occurred on two-lane roads. Only 24% of the crashes with trees occurred in urban areas, and nearly half of those occurred on curved sections of the roadway. This report advocates for clear and specific "clear zone" policies regarding tree placement. A major oversight of the research, however, is its lack of examination of the speeds associated with the crashes; the oversight may have contributed to a confounding of variables, leading to erroneous conclusions about crash causation and an overly simplistic recommendation for how to make highways safer. Future research that controls for vehicle speed, particularly in urban areas, would be helpful.

[31] **Neuman, Timothy R.**, Ronald Pfefer, Kevin L. Black, Kevin Lacy, and Charlie Zegeer. 2003**.** Guidance for the Implementation of the AASHTO Strategic Highway Safety Plan: Volume 3: A Guide for Addressing Collisions with Trees and Hazardous Locations. *NCHRP Report 500*.

Mok and Landphair (2003) compared the accident rates of parallel freeway and parkway sections in different regions across the country.[32] The freeways were characterized by paved shoulders, concrete median barriers, and extended vegetation clear zones; in contrast, the parkways were characterized by grassy shoulders and medians with trees and other landscaping elements within 30 feet of the travel lanes. Data analysis on the numbers and types of crashes on each roadway each year revealed that 9 of the 12 parkway sections were safer than the comparison freeway sections as measured by the fatal accident rate (FAR), defined as the probability of exposure to fatal accidents per 100 million vehicle miles traveled (VMT). Ten of the parkway sections had a lower accident cost than the comparison sections.

Of the types of fatal accidents, those involving the "reflected glare, bright sunlight, and headlights" factors only occurred on freeways. In addition, none of the roadways in this study saw a fatal collision involving trees during the years studied, despite the amount of landscaping. The data also showed that the difference in the average FAR and accident cost between the urban freeway and parkway sections was almost twofold, much larger than the difference between the rural freeway and parkway sections. This difference suggests that landscaping in urban corridors may have a greater safety impact than landscaping in rural corridors.

Dumbaugh (2006) conducted an empirical analysis of the safety of three urban roadside design strategies: widening paved shoulders, widening fixed-object offsets, and providing livable street treatments (on-street parking, trees, sidewalks, and buildings close to the right-of-way).[33] He compared 1999-2003 crash data for 27 miles of these three roadway design strategies in DeLand and Ocala, Florida, after controlling for the roadways' safety performance, consistency of character, ADT, posted speed, number of travel lanes, and lane and median widths. A regression model indicated that unpaved fixed-object offsets had a mixed safety effect, associated with decreased incidence of roadside crashes but slightly increased incidence of mid-block crashes. Wider shoulders were associated with an increase in both roadside and mid-block crashes. Of

[32] Mok J. and H.C. Landphair. 2003. Parkways or Freeways: Safety Performance Linked to Corridor Landscape Type. *Proceeding of Transportation Research Board 82nd Annual Meeting*. Washington, DC. January 12-16, 2003.
[33] Dumbaugh, Eric. 2006. Design of Safe Urban Roadsides: An Empirical Analysis. *Transportation Research Record* 1961:62-74.

the three, only the livable-street treatment was consistently associated with reductions in both roadside and mid-block crashes.

To better understand these findings, Dumbaugh then examined the roadside crash locations for tree and utility pole crashes. Convention states that 80% of crashes involve fixed objects within 20 feet of the roadway, thus implying the standard of a 20-foot clearway. However, Dumbaugh's analysis found that the probability of a tree/pole collision declines at 15 feet. In addition, 65-83% of urban fixed-object collisions did not result from errantly leaving the roadway, as in current thought, but rather failing to properly negotiate a turning maneuver with objects located behind driveways and side streets along higher-speed urban arterials.

Overall, the livable streets study segments exhibited 67% fewer roadside crashes than comparison segments, suggesting that visible fixed-hazards on these roadways segments induce behavioral changes to slow driving speed. An informal "floating car study", wherein Dumbaugh gauged the speed of random cars as they approached and passed through a livable streets intersection with 4-foot. offset street trees, revealed a notable slowing of traffic. This finding suggests that the drivers were reacting to their environment by adjusting their speeds; as the data revealed, no adverse impacts on traffic safety were observed in comparison to the other study sections.

Lee and Mannering (1999) related two years of accident data for a 60-mile stretch of highway in Washington State to the roadside characteristics of its various highway segment configurations.[34] Their analysis revealed a difference between the safety effects of various characteristics on urban and rural roadway sections, as shown in Tables 7 and 8.

For urban highways, the analysis found that wide traffic lanes and wide shoulders are positively associated with a greater frequency of run-off-roadway accidents, whereas the presence of trees is negatively associated.

[34] **Lee, Jinsun** and Fred Mannering**.** 1999. Analysis of Roadside Accident Frequency and Severity and Roadside Safety Management. Washington State Transportation Center.

For rural highways, the analysis revealed a strong correlation between increased rural run-off-roadway crash frequencies and speed limits above 51 mph. In addition, a 10% increase in center median width was associated with a 2% decrease in rural run-off-roadway crashes (the stretch of highway researched contained a variety of median widths, ranging up to approximately 68 feet wide, including the inside shoulder).

Table 7. Urban Roadway Characteristics and Run-off-roadway Crash Frequency

Urban Roadway Sections	
Variable	*Association with run-off-roadway crash frequency*
Travel lanes > 12.1 feet	+
Increased median width	–
Distance from outside shoulder edge to guardrail	+
Fence length	+
Number of isolated trees	–
Number of miscellaneous fixed objects	–
Number of sign supports	–
Increased shoulder length	–

Table 8. Rural Roadway Characteristics and Run-off-roadway Crash Frequency

Rural Roadway Sections	
Variable	*Association with run-off-roadway accidents*
Median width	–
Distance from outside shoulder edge to guardrail	–
Number of isolated trees	+
Higher speed limits	+
Vertical curve length	–
Steeper cut side slopes	+
Distance from outside shoulder edge to light poles	–
Increased shoulder width	–

Analysis of crash type probability revealed that rural areas without any recorded accidents were characterized by wide shoulders. However, roadway sections with shoulder widths less than about 6.4 feet wide were found more likely to result in no-evident-injury collisions. This suggests that on rural highways, a wide clear zone may not always be necessary for safety. In

terms of crash severity, the researchers concluded that it is influenced by a complex interaction of roadside features. Some roadside features appear to contribute to crash injury severity because they contribute to the impact of crashes; others appear to mitigate injury severity, presumably by altering driver behavior and influencing what happens in the crash.

Karlaftis and Golias (2002) studied five years of accident data for rural two-lane and multilane roadways in Indiana to investigate the relationship between highway geometric design and accident frequency on each highway type.[35] Through a review of previous research, Karlaftis and Golias determined that several traffic and design elements affected accident rates, including AADT, highway cross-section design, horizontal alignment, roadside elements, the number of access points and their control, highway pavement conditions, posted speed limit, travel lane width, and median width. The results of the regression analysis indicated that while AADT was the most important factor for both two- and multilane rural highways, controlling for AADT revealed that the most important contributing factors varied according to roadway type. For multilane rural highways, the existence of median width was the most important factor, followed by access control. For two-lane rural highways, vehicle travel lane width was the most important factor, followed by variables related to roadway pavement conditions. Unfortunately, the researchers gave no information on what specific multilane highway median widths or two-lane highway lane widths are most correlated with lower accident rates. Further investigation of the research results could shed light on these questions.

Sullivan and Daly (2005) examined six years of accident data for 58 miles of state highways that served as principal streets in urban and suburban areas in California.[36] The data indicated that the presence of large trees in curbed central medians was associated with increased frequency and severity of left-side accidents, even controlling for speed and the setback of the trees, but with a decreased frequency of head-on and broadside collisions. While the researchers did not theorize about the meaning of these findings when taken together, it seems quite possible that if some of the left-side crashes had not involved a median tree, the vehicle could have

[35] **Karlaftis, Matthew G.** and Ioannis Golias. 2002. Effects of Road Geometry and Traffic Volumes on Rural Roadway Accident Rates. *Accident Analysis and Prevention* 34:347-365.
[36] **Sullivan, Edward C.** and James C. Daly. 2005. Investigation of Median Trees and Collisions on Urban and Suburban Conventional Highways in California. Transportation Research Board. Issue 1908.

crossed the median and gone into on-coming traffic. Because the weighting system the researchers used for accident severity is not clear (i.e., whether a single vehicle crash in which two people die is weighted the same as a two vehicle crash in which two people die), it is difficult to completely understand the full safety impacts, positive or negative, of treed medians. The researchers do conclude that center median widths between 10 and 16 feet wide are associated with fewer left-side collisions than either wider or narrower medians.

In general, the above research studies strongly suggest that the safety effects of roadside trees can not be generalized across all highway types. Rather, their safety impacts apparently vary between controlled access highways, rural highways, and urban arterials.

A number of researchers have studied the effects of roadside landscaping on accident frequency by conducting before and after studies of highways where improved landscaping has been implemented. **Naderi (2003)** investigated the effects on mid-block accidents after landscape improvements were installed along five urban arterial streets in Toronto by analyzing accident data from three years both before and after the improvements.[37] While all the streets carried streetcars or buses and had sidewalks, in other respects they differed considerably: four or six lanes, 50–70 km/hr speed limits (31–43 mph), and 24,000–55,000 ADT. The landscaping improvements differed as well, but generally consisted of sidewalk and center median greening and various types of decorative paving and noise barriers, as well as various arrangements of shrubs, flowers, grasses, and trees and other streetscape elements such as public art or bollards.

Naderi's analysis revealed that on all the streets the landscaping improvements were positively associated with reduced mid-block accident rates, ranging from 5% to 20%. Using a "willingness to pay" formula derived by the Ontario Ministry of Transportation, Naderi found that the landscape improvements quickly proved worth their effort: they led to a savings of over $1 million in reduced traffic crash costs within three years of the decision to implement the $2.5 million in improvements (in 1995 Canadian dollars, $1 Canada = US$0.71685, August 2003).

[37] **Naderi, Jody Rosenblatt.** 2003. Landscape Design in the Clear Zone. *Transportation Research Record* 1851:119-129.

Mok et al. (2003) conducted a before and after study of ten urban arterials in Texas on which landscaping improvements such as roadside and median greening, sidewalk widening, and tree planting were implemented.[38] Examination of three to five years of accident data both before and after the improvements revealed that vehicle crash rates decreased at eight of the ten sites, varying from a 1% reduction to an over 77% reduction. The two sites where crash rates increased post-landscaping were both at highway interchanges; these were the only such sites included in the study, suggesting a need for further research to understand the complexity of interchange design. In addition, for all the highway sections combined, overall tree collisions were reduced by approximately 71% after the landscaping improvements, and pedestrian fatalities decreased by approximately 47%. These findings suggest that there may have been a driver response to the increased amount of landscaping, resulting in improved traffic safety.

St. Martin et al. (2007) compared crash frequency and severity before and after landscape improvements were implemented along approximately two miles of State Route 99 (SR 99) near SeaTac International Airport.[39] SR 99 parallels the interstate highway (I-5), serves as a principal arterial street of the communities through which it passes, and has a posted speed limit of 40–45 mph. Improvements to the roadway were extensive, including converting two-way left turn lanes into landscaped medians with left turn/U-turn pockets, widening the roadway, adding business access and transit lanes, installing street lighting, and making signal improvements. Roadway improvements also included consolidating and defining driveways/access points, undergrounding utilities, and improving stormwater facilities. Pedestrian-oriented improvements included installing sidewalks and pedestrian-scaled features such as better lighting, improved pedestrian crossing points, new or improved transit stops, and aesthetic treatments such as landscaping and street trees. No specific pre- or post-landscaping dimensional information and few details regarding tree-planting arrangements were provided.

The data analysis revealed high crash rates both before and after the landscaping improvements, with no significant change between the two periods. The most salient finding was that the

[38] **Mok, Jeonghun**, Harlow C. Landphair, and Jody R. Naderi. 2003**.** Comparison of Safety Performance of Urban Streets Before and After Landscape Improvements. 2nd Urban Street Symposium, Anaheim, California.
[39] **St. Martin, Anna**, John C. Milton and Mark E. Hallenbeck. 2007. The Safety Effects of Urban Principal Arterial Streetscape Redevelopment Projects Including Street Trees: A Context-Sensitive Case Study.

location of the crashes shifted from mid-block to intersection. In addition, the number of U-turn crashes increased from 4 to 35 within three years. The researchers attribute this to the new restrictions on turning movements due to the removal of the left turn lane. The number of crashes occurring along the first 1.2-mile long section of the highway that was landscaped (Phase 1) decreased by 14% after the improvements. The researchers concluded that the landscaped medians with trees less than 6 inches in diameter did not worsen crash occurrences in the area, and improved the frequencies by some measures. However, along the second 0.75-mile long section of the project (Phase 2), crash rates increased by 53%. The most severe types of crashes decreased, but sideswipes and left-turn crashes increased.

Given that the roadside landscaping was associated with both decreased and increased crash frequencies, the researchers concluded that in both cases the tree variables probably masked other variables such as decreased conflict frequencies or increased access points. They also suspected that crashes with trees were not fully reported, and were thus not fully reflected in the crash rates, and that the youth and corresponding small size of the newly planted roadside trees might have masked their actual potential to cause harm, as tree crashes were mainly classified with "property damage only". In the end, they concluded that the tree variables did not have much effect on crashes either way. The only tangible finding was that trees in narrow center medians may lead to an increase in crashes, although this finding should be understood as pertaining to relatively high speed arterials or state highways like SR99; "narrow median" was not defined by the researchers, but other data suggests that they were approximately 4–6 feet wide. The researchers did not address possible benefits the roadside trees may have conferred by preventing the cars from going into oncoming traffic or onto sidewalks.

The data also indicated that any time access points were increased, including driveways, intersections, and turning points, crash rates tended to increase as well. Shoulders were associated with fewer crashes as their width increased, and shoulder widths greater than 3 feet were significantly associated with reduced crash frequency—a finding at odds with the research previously discussed. The presence of a central median that separated vehicle directional flows was associated with lower crash rates, including those medians containing landscaping. For both phases, pedestrian and bicycle crashes decreased, although the researchers were hesitant to draw

conclusions from this finding due to the low overall rate of such crashes, even though pedestrian activity had increased 15% after the streetscape project was completed.

Conducting a before and after study such as this research effort is a good idea, but the above discussion highlights the difficulty with doing so: when there are multiple changes between the two phases, it is difficult to attribute causation from the findings. Future research that examines a streetscape redesign project where fewer changes were made should allow for greater control over potential confounding of the variables. The authors of the above study recommended examining an existing 4- or 6-lane divided highway with a central median, mid-block turn pockets, and sidewalks, for which roadside and median landscaping work is scheduled.

Some research coming from the field of urban forestry, focusing directly on the impacts of roadside trees on traffic safety, has done a better job of isolating variables. Much of this research offers detailed findings related to the impacts of trees, and also incorporates a nuanced understanding of the importance of different highway contexts—i.e. urban versus rural—resulting in a holistic assessment of the costs and benefits related to roadside trees. For example, **Wolf and Bratton (2006)** conducted a national study of crash data, and their findings suggest that trees might be unfairly blamed for traffic crashes.[40] As Table 9 shows, far less than 1% of the U.S. household trips in 2001 resulted in a crash with a tree. In 2002, only 8,740 of the 6,316,000 total traffic crashes involved a tree and also resulted in serious injury or fatality.

When the data was examined by urban or rural context, it showed that trees were involved in less than 1% of urban accidents, and less than 0.001% of fatal urban accidents. Another interesting finding was that although 62% of all annual miles traveled in the United States were in urban areas, 61% of tree crashes occurred in rural areas. A final finding was that the average speed of crashes involving trees was 14 mph faster than the average speed of all crashes combined, suggesting that the speed likely contributed to the driver losing control of the car and crashing, and that removing trees from near the roadway would not necessarily solve the problem. In fact,

[40] **Wolf, Kathleen L.** and Nicholas Bratton, 2006. Urban Trees and Traffic Safety: Considering U.S. Roadside Policy and Crash Data. *Arboriculture & Urban Forestry* 32 (4):170-179.

the removal of trees could pose more overall risk by removing a buffer between the driver and pedestrians along the roadway.

Table 9. Collision Data for Motor Vehicles and Trees, 2001-2002

	2001	2002
Total trips	229 billion	
Total crashes		6,316,000
Tree crashes	141,000	120,004
Percentage of trips resulting in a collision with a tree	< 0.00001%	
Injury & fatal tree crashes		8,740
Percentage of total crashes involving trees		1.9%
Percentage of total crashes injurious or fatal due to a tree		0.87%

A follow-up report by **Dixon and Wolf (2007)** includes a comprehensive review of the research done to date pertaining to the social, environmental, and economic benefits of trees and their safety risks.[41] The researchers reviewed numerous locally and regionally oriented research studies and found no indication that roadside trees posed a significant or constant safety risk. Instead, their findings suggest that the risk to traffic safety posed by trees may be exaggerated or conflated with other variables, and should be more thoroughly examined for future transportation corridor design.

It is interesting to note the difference between drivers' perceptions of the safety of tree-lined roadways and the assumptions embedded in the strict enforcement of highway clear zone policies that preclude roadside trees in many locations. **Naderi et al. (2008)** investigated how drivers' perceptions of highway safety were affected by the presence of roadside street trees.[42] In a controlled laboratory experiment using a driving simulator, 31 participants took drives along four digitally created streets, two urban and two suburban. The two urban streets were identical

[41] **Dixon, K. K.** and Kathleen L. Wolf. 2007. Benefits and Risks of Urban Roadside Landscape: Finding a Livable, Balanced Response. Proceedings of the 3rd Urban Street Symposium (June 24-27, 2007; Seattle, Washington). Washington, D.C.: Transportation Research Board of the National Academies of Science.

[42] **Naderi, Jody Rosenblatt**, Byoung Suk Kweon, and Praveen Maghelal. 2008. The Street Tree Effect and Driver Safety. *ITE Journal on the Web*. February:69-73.

except that one had no roadside trees while the other had tall, closely-spaced roadside trees. The two suburban streets were identical except that one had no roadside trees and the other had relatively closely-spaced mid-sized roadside trees. For each drive, participants were asked to record their perception of the roadway's safety on a 1 to 5 scale, and their perception of the roadway's spatial definition, on a 1 to 4 scale.

The results indicated that suburban streets with trees were perceived as the safest, followed by urban streets with trees, and that urban streets without trees were deemed to be the least safe. In addition, in both urban and suburban conditions the presence of street trees was associated with greater sense of spatial edge, which then contributed to a greater sense of safety. Data analysis indicated that both city form (urban vs. suburban) and landscaping form (presence or absence of street trees) along the roadway affected the participants' perceptions of safety. However, the presence or absence of street trees had a greater effect on perceptions of safety than did the surrounding land use. The perceptions of safety were matched by a significant drop in the cruising speed of most drivers (an average of ~3 mph) when trees were present on the suburban street, regardless of how fast they drove on the non-treed suburban street. The speed data obtained for the urban streets could not be successfully analyzed because the results were confounded by the presence of short block lengths.

These findings, in conjunction with findings from the other studies reviewed in this chapter, seem to suggest a different role for trees in the urban and suburban landscape – one that confers traffic safety rather than threatens it. Trees along the roadside will likely still be inappropriate at certain locations, but perhaps they will benefit other locations more than previously realized. Given that trees also tend to confer multiple environmental and aesthetic benefits, these findings could spur a new trend toward designing truly context sensitive solutions for Caltrans roadways in its partner communities. This could mean planting street trees more regularly and lowering design speeds to allow for more landscaping and pedestrian-activity generators.

Street Trees and Intersection Safety

Engineering geometric design policy manuals, such as those of the American Association of State Highway and Transportation Officials (AASHTO), recommend designing urban arterial

street intersections with clear sight triangles in order to improve a driver's ability to see potential conflicts with other vehicles before entering an intersection. These triangles extend hundreds of feet beyond the intersection. Within the clear sight triangles, the recommended design solution is to eliminate any object above sidewalk level that would intrude into the sight triangle and interfere with a driver's vision, *where practical.*[43]

Traffic and highway engineering textbook examples describing the clear sight triangle concept generally show diagrammatic plan views of intersections with sidewalk trees indicated as the objects to be eliminated from the sight triangle. In the diagrams, trees are represented as solid circles, implying that they are solid cylinders from top to bottom.[44] This representation is of course unrealistic because street trees are typically trimmed to have only high branches. Although the intent of the clear sight triangle idea is to eliminate physical elements from a driver's cone of vision, the triangle is conceptualized in two-dimensional terms rather than three-dimensional terms. In reality, the part of a street tree that would intrude on a driver's central cone of vision is the trunk, a relatively thin vertical element.

In practice, the engineering policy recommendations regarding intersection clear site triangles, and the embedded assumptions that street trees are the things that must be eliminated from them, has resulted in many cities adopting street design standards that include large set-back restrictions on sidewalk trees at intersections that often apply regardless of how a given intersection is controlled, while similar hold back regulations are not put in place for other things that commonly occur on sidewalks near intersections, such as newspaper racks, traffic signal poles, streetlights or parking meters. Furthermore, urban street design ordinances generally do not require holding on-street parking spaces back a large distance from an intersection, so in practice parking spaces often come right up to the stop limit line or backside of the crosswalk. Experientially, it is more often these larger, latter objects (parked cars and newspaper stands) that

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[43] **American Association of State Highway and Transportation Officials**. 2004. *A policy on geometric design of highways and streets.* Washington D.C.: American Association of State Highway and Transportation Officials.
[44] **Garber, Nicholas J.** and Lester A. Hoel. 1997. *Traffic and Highway Engineering, 2nd Edition.* Boston: PWS Publishing Company.

block driver vision at intersections. The result is a streetscape that is still unsafe, due to these objects blocking sightlines, and is also less pleasant, due to the prohibition on trees.

In sum, engineering policy recommendations regarding clear sight triangles have resulted in vigorous limitations on street trees near intersections but little regulation of other possible obstructing elements.

In order to investigate whether or not street trees near intersections are the safety problem they are purported to be, or whether other physical, controllable qualities more important for preserving sight lines at intersections, **Macdonald (2006)** conducted a study using advanced computer modeling techniques.[45] Three digital models of a typical urban intersection were created in which the basic configuration was kept constant but locations of sidewalk trees, parked cars, and newspaper racks varied. The variations of these elements reflected AASHTO recommendations, the actual standards in place in one California city (Oakland) and a pedestrian-friendly option. The models were then animated with moving cars, and drive-through simulations from a driver's viewpoint were created. These simulations were turned into videos, which were shown to participants in controlled laboratory experiments. The participants were asked to identify when they were able to first see particular test cars, and to fill out a short questionnaire. The results of the experiments were compiled and analyzed to determine the perceived visibility impacts of the various model configurations.

The basic conclusion of the research was that street trees—if properly selected, adequately spaced, and pruned for high branching—do not create a strong visibility problem for drivers entering an intersection. Rather, on-street parked cars, particularly large ones such as SUV's, create substantially more of a visibility problem. As well, newspaper racks near intersections appear to create some visibility problems. The research suggests that street trees planted close to intersections and spaced as little as 25 feet apart, pruned so that horizontal limbs and leafing start about 14 feet off the ground, do not constitute a visibility safety hazard on urban streets.

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[45] **Macdonald, Elizabeth.** 2006. *Street Trees and Intersection Safety* (Working Paper 2006-11), Berkeley, CA: University of California at Berkeley Institute of Urban and Regional Development: 103 pages.

Summary of Key Research Findings

The following is a summary of the key findings on the research related to corridor roadside design and driver safety:

From the many studies cited above it is difficult to come to unequivocal conclusions regarding the safety effects of roadside design elements along highways and arterial streets, whether in rural or urban environments, in large measure because there are so many variables associated with most of the studies. That being said, some conclusions are possible, although they are at times less definite than we would like.

- Higher driver speeds are more associated with vehicle crashes and fatalities than are slower speeds.
- Wider lane widths are more likely to be positively related to higher driver speeds than narrow lane widths.
- Visual guidance in the form of painted edge lines tends to increase driver speeds.
- Landscape elements within the roadsides of urban corridors seem to have greater positive safety impacts than those along rural corridors.
- None of the studies seem to show, unequivocally, that trees and other landscape elements negatively impact safety.
- Driver perception studies seem to suggest that drivers perceive roadside trees as being associated with safety.
- Research related to the impacts of roadside trees on the frequency and severity of run-off roadway accidents does not seem to adequately address or deal with critical questions of crash causation, particularly the confounding variables of driver speed, intoxication level, and fatigue.
- In a modestly mixed bag of findings, it is easier to associate roadside trees with slower speeds and safety than the opposite.
- Street trees near the intersections of urban arterials do not seem to cause the visibility problems that have been attributed to them. However, on-street parking near intersections seems does seem to cause visibility problems.

Future Research Needs

In order to understand more fully how corridor roadside design elements contribute to driver safety, additional research would be useful. First, it seems clear that more research is needed to better understand the complex nuances between roadside design, roadbed design (particularly lane widths), and driver speed.

- The European concept of "environmental reference speed" seems a promising way to study the impacts of roadside design elements. Findings associated with reference speed have suggested that roadways with sidewalks and street trees tend to result in fewer collisions and fatalities.
- There is a need for more research on the impacts of urban arterial lane widths on driver speed and roadway user safety.
- There is a need for case studies in which variables are carefully controlled for, particularly those in which the presence or absence of trees or other roadside landscaping is the key variable.
- Studies further examining the causation of run-off roadway crashes, particularly those involving trees, are called for.
- Certainly there must be long stretches of rural and urban arterials where on the same roadway there are some sections with trees and some sections without. Those are roadways to be studied. Parallel roadways with similar right-of-way configurations and carrying roughly the same amount of traffic, but where the roadside landscaping characteristics vary, could also be case studies.
- Studies aimed at further investigation of the visibility impacts of street trees and on-street parking near intersections on urban arterial streets would be helpful.

Pedestrian Safety

Many studies about traffic safety focus on drivers, but pedestrian safety is equally important; according to the National Highway Traffic Safety Administration, over 4,700 pedestrians were killed in the United States in 2006, and 61,000 were injured.[46] In California, nearly 17% of the traffic fatalities were pedestrians, among the highest levels in the nation. Researchers who have been looking at pedestrian safety have focused on a number of different concerns having to do with traffic calming, crosswalk design, and intersection conflicts between pedestrians and vehicles, all of which, together with special concerns related to children, are covered in this section.

Traffic Calming

The connection between pedestrian safety and traffic calming seems self-evident: traffic calming is needed in places where both vehicles and pedestrians are present. Interestingly, traffic calming interventions seem particularly important where fewer numbers of pedestrians are present, as the sheer presence of large numbers of pedestrians seems to encourage drivers to drive more slowly. Looking at five data sets from California, the United Kingdom, and other European countries, **Jacobsen (2003)** examined the relationship between the number of people walking or cycling and the frequency of collisions between motorists and pedestrians or cyclists.[48] The data from California and the Netherlands revealed that the likelihood of an injury is not constant, but rather decreases as walking or bicycling increases. Data from the UK and other European countries indicate that the number of bicycling fatalities/distance decreased with an increasing distance bicycled per capita.

Across all geographic locations, the total number of walkers and cyclists hit by motor vehicles varies with a 0.4 power of the amount of total walking or cycling, thus the presence of more pedestrians and bicyclists leads to fewer collisions. These findings suggest that motorists become more visually aware and cautious of bicyclists and pedestrians as their numbers increase.

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[46] National Highway Traffic Safety Administration. Traffic Safety Facts – 2006 Pedestrian Data. 2006.
[48] **Jacobsen, P. L.** 2003. Safety in numbers: more walkers and bicyclists, safer walking and bicycling *Injury Prevention* 9:205-209.

However, in many situations, physical traffic calming measures appear necessary to slow driver speeds. To this end, many transportation researchers are seeking to understand where traffic calming efforts lead to improved pedestrian safety and what design elements have the biggest impact. Table 10 provides an overview of traffic calming techniques currently used in the U.S. Appendix I contains a breakdown of appropriate traffic calming techniques per roadway type.

Table 10. Common Traffic Calming Techniques

Type	Treatment	Definition
Vertical: use forces of acceleration to discourage speeding	Speed **hump**	Rounded, raised areas placed across the roadway to slow speed. Recommended length of 12–14 feet in the direction of travel, with a 3–4 inch height. Shape can be parabolic, sinusoidal, or circular. ITE recommends a 12-foot parabolic hump to achieve an 85th percentile speed of 15–20 mph.
	Speed **bump**	Smaller versions of the speed hump: 1–3 feet long and 3–6 inches tall. Used mostly in parking lots and private roadways, where speeds should be very low.
	Speed table	Modified speed hump with a flat top that allows the wheelbase of a passenger car to rest on top. Provides a gentler slope than speed humps, but less reduction in speed can be expected.
	Textured pavements	The use of brick and other special pavers to cue drivers about pedestrian territory by altering the feel of the road.
Horizontal: force drivers to reduce speeds by impeding straight-through movements	Traffic circle	Raised island in the middle of an intersection, around which traffic circulates. Meant to prevent driver speeding by making it difficult to pass straight through intersections. The minimum diameter should be 24 feet; 26-33 feet is preferred. A truck apron can be added to facilitate movement through the intersection by larger vehicles. Often used with lower-speed roads (≤ 35 mph) with lower volumes of traffic (300-3,000 ADT).
	Roundabout	Much larger version of a traffic circle; provides yield control to all entering vehicles and channelized approaches, so can support a higher ADT (over 20,000 in some cases). Generally designed to encourage travel speeds to be less than 30 mph, but can have two travel lanes. Diameters range from 45-200 feet, depending on the number of lanes, speed, and ADT.
	Chicane	Curb extensions that create an S-shaped curve on a street. Not always considered effective, as a driver can maintain

		speed and drive down the center line if there is no oncoming traffic. Another option is to alternate on-street parking from one side of the street to the other.
Road narrowing: elicits a psychological sense of enclosure to discourage speed	Center island narrowing	Raised island along the centerline of a street that narrows the travel lanes at that location. Often used on curves where speeding is common, or downstream of intersections. The island can act as a pedestrian refuge.
	Choker	A narrowed roadway formed by extending the curb on both sides of the street. The curb extensions can be placed parallel to one another, or at an angle.
Psycho-perception control: "play(s) upon ingrained driver responses to certain stimuli to induce or even trick them into a desired behavior …or to heighten driver response"	Edge lines	Painting edge lines several feet from the pavement edge can visually narrow the roadway and possibly lead to a reduction in speed.
	Transverse markings	Transverse lines are painted across a driving lane, horizontal to the direction of travel. Typically placed at hazard locations, they are meant to alter the driver's perception of current speed. As the lines are painted closer and closer together, the driver is supposed to perceive this as his own increase in speed, and therefore slow down to counteract this increase.
Speed Management: techniques used to reinforce desired speed when other traffic calming techniques are not appropriate, such as on higher speed roadways	Increased enforcement	The use of police officers to encourage compliance with lower speed limits in target areas. Although found to be very effective, may last only as long as personnel are present.
	Citizen speed watch	Local citizens monitor vehicle speed in the community and inform fast drivers of the need for speed limit compliance.
	Speed trailers	Measure and display the speed of approaching vehicles to inform drivers of possible speed limit violations.
	Automated enforcement	A camera is used to capture the license plate of the driver violating the speed limit or law; a ticket is sent via mail.

Litman (1999) reviewed over 100 research studies and other pieces of literature related to traffic calming, with the goal of synthesizing the findings and creating a framework to delineate the costs and benefits.[50] A major finding was that 85% of pedestrian fatalities occur on non-local streets such as arterials, and that speed is the main culprit. The report suggested that thorough traffic calming (i.e., multiple, site-specific measures) would lead to increased traffic safety – directly, through slower automobile traffic, and indirectly, through greater numbers of pedestrians and bicyclists (likely leading to increased driver awareness).

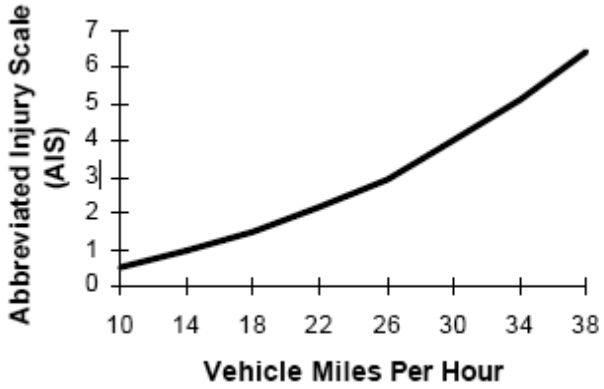
[50] **Litman, Todd**. 1999. Traffic Calming Benefits, Cost and Equity Impacts. Victoria Transport Policy Institute, December 7.

Litman quoted a study by Leaf and Preusser (1999), who examined the relationship between vehicle travel speeds and resulting pedestrian injury. Their data indicated that higher vehicle speeds were strongly correlated with serious pedestrian injuries and a possible increase in the occurrence of pedestrian crashes. Past research has shown that the speed at which a car strikes a pedestrian almost conclusively decides whether or not the pedestrian will live, as shown in Table 11 and Figure 1.[51, 52]

Table 11. The Relationship between Speed of Motor Vehicle and Pedestrian Survival

Speed of Motor Vehicle Upon Hitting Pedestrian	Likelihood of Pedestrian Survival
20 mph	~ 95%
30 mph	~ 60%
40 mph	~ 20%
50 mph	~ 0%

Figure 1. Vehicle Impact Speed Versus Pedestrian Injury



The Abbreviated Injury Scale is an anatomical scoring system used to rank injury severity; it has the following values:
1 – Minor
2 – Moderate
3 – Serious
4 – Severe
5 – Critical
6 – Unsurvivable

This relationship between survival and force of impact has been attributed to the biological limitations of the human body – humans can run about 20 mph at top speed, so falling and hitting

[51] As quoted in Litman, 2004:
Leaf, W.A., & Preusser, D.F. *Literature Review on Vehicle Travel Speeds and Pedestrian Injuries*. Final Report, DOT HS 809 021, October 1999. Washington, DC: National Highway Traffic Safety Administration.
[52] *Traditional Neighborhood Development Street Design Guidelines*, Institute of Transportation Engineers (Washington DC; www.ite.org), June 1997, p. 18, as quoted in Hamilton-Baillie, Ben. 2004. Urban Design: Why don't we do it in the road? Modifying traffic behavior through legible urban design. *Journal of Urban Technology*. 11(1): 43-62. Abbreviated Injury Scale. Association for the Advancement of Automotive Medicine. http://www.trauma.org/archive/scores/ais.html. (Oct. 7, 2008).

one's head at this speed is survivable. The problem is that continued innovation with regard to safety inside cars – seatbelts, air bags, etc. – has allowed cars to travel at relatively high speeds without much risk, but few precautions have been taken for pedestrians. Improving safety for pedestrians by limiting the places they can walk is unacceptable from social equity, quality of life, and physical health standpoints; addressing the speed of cars, and why they are allowed to travel through pedestrian areas at speeds that can result in serious injury or death, should be a critical agenda item for pedestrian safety in the coming years.

Garder et al. (2002) investigated types of traffic calming measures that were being implemented in countries around the world and people's perceptions and acceptance of them.[53] Their mixed methods included an extensive review of international traffic calming practices and their outcomes, a survey of 183 residents in Connecticut about their perceptions of traffic calming elements, and interviews with public officials of 12 Maine cities to assess their opinions of traffic calming measures. They found that in European locations where the ADT ranged from 4,000 to 15,000, well designed, circular intersections have slowed traffic and reduced crashes by 50-90% in some cases, in addition to reducing mid-block speeds by 10%. A similar level of injury accident reduction has been documented following the implementation of roundabouts on highways in North American cities with similar ADT. The researchers examined traffic calming techniques in New England and found that modern U.S. roundabouts significantly reduced the incidence of fatal and serious injury crashes, even with a higher ADT post-installation; the researchers believe that the reduction in crashes is due to the reduction in speed associated with the roundabouts. (While these findings indicate that roundabouts can contribute to traffic calming, further inquiry into the specifics of roundabout design—i.e. single lane versus multi-lane—is not pursued in this literature review because of the focus on roadside design.)

The researchers also looked at traffic calming measures in Portland, Maine, and Victoria, Canada; both cities used a combination of traffic calming measures to achieve the lowered speeds.[54] Portland installed bike lanes, medians, raised crosswalks/intersections, and two speed tables, with the result that some speeds were lowered by 15 mph. In Victoria, on-street parking

[53] **Garder, Per**, John N. Ivan and Jianhe Du. 2002. Traffic Calming of State Highway Application New England. Department of Civil and Environmental Engineering, University of Maine.
[54] Ibid.

and pedestrian refuge islands were installed, and speeds were lowered by 3 mph. Other research has found that in Norway, area-wide traffic calming schemes have reduced injury accidents by 15%. These findings corroborate the evidence that traffic calming using multiple measures can lead to an outcome of lowered automobile speeds and greater traffic safety.

Topp (1990) conducted a study of nine urban thoroughfares in Germany to examine the techniques used to protect pedestrians and mitigate traffic safety risks.[55] In one case, he found that the elimination of street markings and introduction of a pedestrian island reduced pedestrian accidents by 80%. On streets with heavy automobile and pedestrian traffic, he found that the combination of a reduction in speed with a center median offered the most effective strategy for safety. The reduction of perceived roadway width was found to functionally lower speeds and separate modes. Street trees were identified as the most influential element in reducing perceived roadway width because their verticality helped segment the roadway into different sections. These findings suggest that strategies to narrow the perceived roadway width, which can be accomplished through a variety of methods, could be an effective way to lower traffic speeds and increase traffic safety.

A comprehensive review of the effectiveness of traffic calming devices conducted by **Daniel et al. (2005)** concluded that speed humps were the most effective measure for reducing vehicle speeds in many cases.[56] A before-and-after study of 730 speed humps in Gwinett County, Georgia, revealed an average speed decrease of 24% (9.1 mph) after speed humps were installed; the best performance was found with speed humps measuring 3 inches tall and 12 feet long. A study of speed humps in Boca Raton, Florida, found that a combination of an 18–foot narrowed roadway and a 4–inch tall speed table reduced 85th percentile speeds at one location by 12 mph at the speed table and 5 mph 200 feet away; a second location showed speed reductions of 10 and 3 mph, respectively. Perhaps most convincing was an ITE study that examined traffic calming techniques in 20 different cities and concluded that speed humps were the most effective, with an average reduction in 85th percentile speed of 7.6 mph.

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[55] **Topp, Hartmut H.** 1990**.** Traffic Safety, Usability and Streetscape Effects of New Design Principles for Major Urban Roads. *Transportation* 16:297-310.
[56] **Daniel, Janice**, Steven Chien, and Rachel Liu. 2005. Effectiveness of Certain Design Solutions on Reducing Vehicle Speeds.

Daniel et al.'s review also identified roundabouts as being particularly effective traffic calming devices. One study of several roundabouts in Maryland found that 85th percentile speeds were reduced from 40 mph to 20–22 mph after their installation. Another study found that traffic crashes dropped from 35 to 13 after the roundabouts were installed. The chicane, on the other hand, was deemed a "questionable" traffic calming measure, due to mixed findings from studies. However, the researchers found that roadway narrowing through the implementation of a center median was found to be effective in Canada, where a before-and-after study showed a speed reduction of approximately 3 mph after installation, and the number of vehicles exceeding the speed limit was reduced by 20%.

Daniel et al.'s conclusion that speed humps are the most effective device for reducing speed is supported by studies beyond those cited by the researchers. In general, research has found that speed humps are associated with reduced 85th percentile speeds, and sometimes with reduced traffic volume.

Huang and Cynecki (2001) assembled and summarized the key findings of several research studies on traffic calming.[57] A before and after study of 10 speed hump locations in Omaha, Nebraska, found a significant reduction ($p < .05$) in 85th percentile vehicle speeds. A study of 16 speed humps in Bellevue, Washington, showed a decrease in 85th percentile speeds of 12 mph (from 36–39 mph to 24–27 mph) after installation. If alternate routes existed, traffic volumes fell correspondingly. Another study of speed humps in Montgomery County, Maryland, showed a typical 85th percentile speed reduction of 4–7 mph. The speed humps were also associated with a reduced accident frequency, although there was no significant effect on traffic volumes. Data collected on speed humps in Howard County, Maryland, showed an 85th percentile speed reduction of 9 mph (from 32 to 23 mph). Speed humps installed in Agoura Hills, California, were associated with a drop in speed of 6–9 mph (these humps were 0.25 inch lower than the customary 3-inch height). Three Australian cities—Corio, Croydon, and Stirling—saw 85th percentile speeds drop by at least 50% at locations where speed humps were installed. In

[57] **Huang, Herman F.** and Michael J. Cynecki. 2001. The Effects of traffic calming Measures on Pedestrian and Motorist Behavior. Federal Highway Administration.

addition, vehicle speeds dropped by 25–33% between sequential hump locations, and daily traffic volumes decreased by 25–50%.

Taken together, the above research studies suggest that traffic calming is accomplished by a combination of roadway and roadside design elements. Roadway design that includes roundabouts and speed humps seem effective; roadside design that includes medians and trees is also effective.

Rather than trying to assess which individual traffic calming measures are the most effective at reducing speeds, some researchers are looking at the safety impacts of various traffic calming "bundles." **Ossenbruggen et al. (2001)** studied 87 two-lane undivided highways in New Hampshire to assess the comparative safety of highway segments of three different types, defined by both adjacent land use and highway configuration.[58] The highway types were: rural residential (4 dwelling units/acre or less, no sidewalks, no traffic controls, no on-street parking, posted speeds generally over 30 mph, some posted speeds of 45 mph); village "main street" (sidewalks, crosswalks, on-street parking, stop signs, mixed land use, posted speeds of 30 mph or less, large amount of pedestrian traffic); and commercial strip (no sidewalks, no traffic controls, wide curb cuts or no curbs at all, no on-street parking, 40% with posted speeds over 30 mph).

The researchers found that, in absolute terms, the highest number of total and injury crashes occurred at strip commercial sites, followed by rural residential. The least amount of crashes occurred at the village "main street" sites. When adjusted for traffic flows, village "main street" sites still had fewer crashes than either rural residential or commercial strip sites. Only 9% of the pedestrian injury crashes occurred in the village zones as compared to the shopping strip, which had 39% of the pedestrian injury crashes, and the rural residential, which had 52% of the pedestrian injury crashes – including four fatalities. The absence of sidewalks and high vehicular exposure were cited as reasons for the high number of crashes and injures at shopping sites, whereas the absence of sidewalks and high speeds were cited as reasons for the high number of crashes and injuries in rural residential areas. These findings strongly support the

[58] **Ossenbruggen, Paul J.**, Jyothi Pendharkar and John Ivan. 2001. Roadway safety in rural and small urbanized areas. *Accident Analysis and Prevention* 33: 485–498.

argument for pedestrian facilities and traffic calming measures to enhance pedestrian safety or state highways that run through communities, particularly rural areas where pedestrian volumes may be naturally low.

Ivan et al. (2001) conducted two studies to better understand the influence that combinations of different highway design elements had on different highway types.[59] The first study investigated randomly selected urban arterial streets in seven small cities in Maine, comparing five years of pedestrian crash data for each, and correlating this with highway design, speed, and pedestrian and vehicle volume count data obtained through fieldwork. All study streets had a posted speed of 25 mph, and the median AADT was just below 6,000 vehicles per day. The researchers found that driver speed is highly inversely correlated with a propensity to yield to a pedestrian in a crosswalk. Driver speed of less than 11 mph led to 100% yielding, compared to only 28% yielding at speeds 11–15 mph, 23% yielding at 16–20 mph, and 17% yielding at 21–30 mph. In addition, the data suggested that marked crosswalks were about 46% safer than unmarked crosswalks, although marked crosswalks at signalized locations were shown to be about 26% more dangerous than crosswalks at unsignalized locations. The authors stress that this could be the result of covariation within the model – that it may be the locations themselves that are dangerous, rather than the crosswalk treatment.

The second study investigated the relationship between roadway characteristics and vehicle/pedestrian crashes on two-lane rural highways in Connecticut by analyzing ten years of pedestrian crash data and creating a model of injury severity.[60] The researchers found that neither roadway width nor the presence or absence of on-street parking was significant in terms of injury severity. However, highway segments classified as downtown and "compact" (higher-density) residential were associated with lower injury severity than those segments in low-density residential areas, likely due to higher vehicle speeds in the lower density areas. The researchers concluded that speed-reducing measures—such as narrower roadways—should be considered for village and downtown fringe areas where speeding tends to occur, because these

[59] **Ivan, John N.**, Per E. Garder, and Sylvia S. Zajac. 2001. Finding Strategies to Improve Pedestrian Safety in Rural Areas – Parts 1 and 2. Region 1 University Transportation Center. U.S. DOT.
[60] Ibid.

areas typically experience higher pedestrian injury severity than either downtown, compact residential, medium-density commercial, or low-density commercial areas.

Some professionals advocate the use of angled parking for traffic calming along arterial main streets. While the effectiveness of this treatment has not yet been well studied, some research has looked into its safety impacts. **Souleyrette et al. (2003)** evaluated the safety effects of angled parking on two-lane highways in 29 small towns in Iowa, in order to better understand the associated risks of using angled parking as a traffic calming measure.[61] Prior studies have considered angled parking a traffic safety hazard, but it has recently been reconsidered as a tool to slow traffic in rural downtown areas. The researchers found that population was the only significant factor related to crash history, and that the difference between parallel and diagonal parking with regard to crash propensity was negligible. In addition, fewer crashes occurred in areas with parking than in areas without parking, leading the researchers to conclude that parking can be an effective traffic calming measure, and that there is not a strong justification for the prohibition on angle parking. Because this research was conducted in towns with ADT of 2,400–8,900 (averaging 5,039) it should be taken with caution in larger areas. However, it is applicable for Caltrans jurisdictions that tend to be more rural and therefore have lower traffic volumes.

Traffic calming may be a particularly important strategy for the safety of children. **Cross and Mehegan (1988)** conducted a study on young children's perceptions of speed with regard to moving automobiles.[62] They studied 175 children aged 4–9 years using play techniques to identify patterns in children's perceptions of speed, time, and distance. They found that children under age 6 have a naïve conception of distance and speed, and do not relate the two. In addition, a significant percentage of the children aged 6–9 lacked a comprehensive understanding of more complex circumstances involving distance and speed. Follow-up research showed that these perceptions affect the manner in which children cross streets, and suggest that although children make decisions they deem rational with regard to traffic, their limited

[61] **Souleyrette, Reginald R.**, Thomas J. McDonald, and Ryan Tenges. 2003. Angle Parking on Iowa's Low Volume Primary Extensions in Small Towns. Center for Transportation Research and Education. Iowa State University.
[62] **Cross, Roger T.** and Julie Mehegan. 1988. Young Children's Conception of Speed: Possible Implications for Pedestrian Safety. *International Journal of Science Education.* 10 (3):253-265

understanding of the concepts of speed, time, and distance may put them at risk. It therefore becomes the responsibility of the transportation planners and engineers to design roadway corridors that facilitate safety, in addition to the education and enforcement programs for children, such as Safe Routes 2/To School.[*]

Crosswalks

A considerable amount of research has been done on pedestrian safety associated with crosswalk design. So much so that it has been included here because of likely, or even possible, connections to roadside design. Crosswalks provide the pedestrian linkage from one roadside to another, and design elements may include such things as corner or mid-block sidewalk widenings that are clearly part of the roadside design.

Researchers have focused specifically on the safety effects of various traffic calming crosswalk treatments because of the high potential for vehicle and pedestrian conflicts to occur at places where pedestrians cross roadways. In addition, there is a desire to understand what crosswalk design elements contribute to both general traffic calming and an increase in drivers giving pedestrians the right-of-way. In 2002, nearly 23% of motor vehicle/pedestrian crashes in the U.S. occurred while pedestrians were in a crosswalk, and over 96% of these accidents occurred at intersections.[63] Alarmingly, approximately one-third of these crashes resulted in severe or fatal injury. The majority of research on crosswalks has found that the implementation of multiple treatments at one site is the most effective way to change driver-yielding patterns and encourage pedestrian compliance.

Knoblauch et al. (2001) conducted before and after studies of 11 crosswalks in cities across the United States (Sacramento, California; Buffalo, New York; Richmond, Virginia; and Stillwater, Minnesota), to determine the safety effects of implementing a simple marked crosswalk at an unsignalized intersection where none had previously existed.[64] All of the intersections studied were on straight and level roadways with excellent sight distances, speed limits of 25 mph or

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[*] Safe Routes 2 School is the California-specific program; Safe Routes To School is the national program.

[63] As quoted in Ragland and Mitman, 2007:
Statistics from the National Automotive Sampling System and General Estimates System 2002.

[64] **Knoblach, Richard L.**, Marsha Nitzburg, and Rita F. Seifert. 2001. Pedestrian Crosswalk Case Studies: Sacramento, California; Richmond, Virginia; Buffalo, New York; Stillwater, Minnesota.

less, and low volumes of traffic. The researchers found that no changes in traffic volumes or traffic gaps occurred after the crosswalk markings were installed, but that drivers approached the crosswalks with slightly reduced speeds. However, the percentage of drivers who yielded to pedestrians did not change. As well, they found that at all the intersections except two in Buffalo, pedestrian crosswalk usage increased after marked crosswalks were introduced, with some increasing as much as 36%.

Huang and Cynecki (2001) conducted before and after studies of various pedestrian crossing treatments installed in eight US cities—seventeen treatments in all—with half of the studies also including comparisons with control sites where no treatments were installed.[65] The crossing treatments included bulb-outs, pedestrian refuge islands either alone or with zebra (also known as "piano key") crosswalks, raised crosswalks, and a raised crosswalk combined with an overhead flashing warning light. Street types included urban arterials, collectors, and neighborhood streets; most carried two-way traffic. Data was collected during weekday daylight hours via video cameras, direct observations, and speed measuring devices. Analysis was done according to three measures of effectiveness: average pedestrian wait time, percentage of pedestrians crossing at the crosswalk versus elsewhere along the block; and the percentage of pedestrians for whom motorists yielded.

The researchers found that the effectiveness of the various treatments was mixed, although vehicle speeds were typically lower at treatment sites than at control sites. The most significant effects were found where multiple treatments were installed. In particular, the combination of a raised crosswalk with an overhead flasher increased the percentage of pedestrians for whom motorists yielded and resulted in significantly greater speed reductions than a raised crosswalk alone (3–6 times as much reduction); none of the other treatments had a significant effect on the percentage of pedestrians for whom motorists yielded. None of the treatments was found to have a significant effect on average pedestrian waiting time. In one case, the implementation of a raised crosswalk at an intersection where a marked crosswalk existed previously resulted in an increase in the percentage of pedestrians who crossed in the crosswalk by nearly 27% (from 11.5% to 38.3%). Where median refuges were installed the percentage of pedestrians crossing at

[65] **Huang** and Cynecki, 2001.

the crosswalk increased significantly, indicating that refuge islands may help channel pedestrians into marked crosswalks.

Dulaski (2006) studied three intersections along a two-lane urban arterial highway in Amherst, Massachusetts that had received multiple traffic calming treatments.[66] The treatments included narrowed travel lanes (from 12 to 11 feet), pedestrian refuge islands, textured crosswalks with pedestrian-activated, in-roadway warning lighting, 4-foot wide marked bike lanes, and advance yield signage. Dulaski found that vehicle speeds were slightly reduced after the treatments were installed, although the reduction was less in the northbound direction where vehicles had a slight hill climb. Before the treatments, pedestrian crosswalk compliance averaged 54.2% across the three intersections; it rose to 96.2% after treatments were installed.

In order to study pedestrian behavior, preferences, and perceptions regarding crosswalks, **Sisiopiku and Akin (2003)** studied a one-kilometer length of an urban arterial in East Lansing, Michigan.[67] Adjacent to Michigan State University, this section included new installations of several crosswalk treatments at various locations. The street was a divided boulevard with an AADT of approximately 32,000. Although the authors did not give lane configuration specifics, the diagrams included in the article indicated there were two travel lanes in one direction and three travel lanes in the other direction, but no parking lanes. Five signalized intersections had red brick crosswalks; two unsignalized intersections had striped crosswalks; four mid-block locations had marked crosswalks; and two mid-block crossing locations were unmarked. Some locations had pedestrian crosswalk shelters and pedestrian warning signs messaging ‘‘cross only when traffic clears.” Some sections of sidewalk had physical barriers consisting of vegetation and a two-foot high concrete wall, which were intended to discourage pedestrian crossings outside of the crosswalk.

Using video cameras mounted along the street in strategic locations, the researchers recorded pedestrian movements during the noon peak and PM peak hours, mostly on weekdays, although

[66] **Dulaski, Daniel M**. 2006. An Evaluation of Traffic Calming Measures and Their Impact on Vehicular Speeds on an Urban Principal Arterial Roadway on the Periphery of an Activity Center. ITE Annual Meeting and Exhibit Compendium of Technical Papers.
[67] **Sisiopiku, V.P.** and D. Akin. 2003. Pedestrian Behaviors at and perceptions towards various pedestrian facilities: An examination based on observation and survey data. *Transportation Research Part F* 6:249-274.

sometimes on the weekend, avoiding inclement weather if possible. In addition, they surveyed crosswalk users, gathering 22 surveys on-site and another 711 from random affiliates of the University who were screened to ensure they actually used the crosswalks under study.

The researchers concluded that well-designed and placed pedestrian crossing facilities can encourage pedestrians to concentrate their crossings at certain desired locations, with those that are mid-block being the most influential. From the video footage, they determined that within the study area as a whole, 59% of pedestrians crossed the street within crosswalks, while the remaining 41% crossed at any convenient location. At signalized locations, 45% of pedestrians crossed when an acceptable gap occurred whereas 10% waited for a pedestrian green signal. In other words, signalized intersections with pedestrian-activated signals and crosswalks helped channel pedestrian traffic, but proved unable to persuade pedestrians to comply with the signal indication, particularly under low traffic demand conditions.

The survey results indicated that the unsignalized mid-block crosswalk was the crosswalk treatment most preferred by pedestrians (83% of the respondents reported a preference to cross at them), mirroring the field observations, which found such crosswalks to have a very high pedestrian crossing compliance rate (71.2%). In general, pedestrians considered the pedestrian-directed warning signs ("cross only when traffic clears") at the unmarked mid-block crosswalks annoying. The researchers concluded that generally a pedestrian's decision to cross at a designated crossing or not was most influenced by the proximity between the crossing and the desired destination on the other side. Added convenience was the number one reason for crossing outside of the crosswalk (cited by 90% of the survey respondents). These results indicate that positioning mid-block crosswalks near land uses that generate or attract pedestrian traffic has the potential to significantly improve pedestrian compliance rates. The survey results further revealed that the presence of a pedestrian activated signal at a designated crossing encourages pedestrians to cross there (according to 74% of the respondents). In addition, the survey and field observations combined revealed that the presence of crossing barriers—such as the concrete barriers with vegetation that were installed at some places along the case study street—convinced a significant number of pedestrians not to cross there (according to 65% of the survey respondents).

Perhaps the most troubling finding of the research was that at signalized intersections, the majority of motorists turning either right or left failed to give priority to pedestrians during the pedestrian green phase. The researchers concluded that this type of motorist behavior substantially increased the likelihood that a pedestrian would decide not to cross at signalized crosswalks during green, if the pedestrian could identify a crossing alternative that they felt would reduce their delay and provide safer crossing conditions. This finding strongly suggests that that when significant motorist turning movements and/or significant pedestrian crossing volumes exist, the use of leading pedestrian intervals could improve safety as well as pedestrian crossing compliance.

There is much concern among highway designers about whether marked or unmarked crosswalks are safer at unsignalized locations. **Fitzpatrick et al. (2006)** published a major report on unsignalized crossings for the National Cooperative Highway Research Program and Transit Cooperative Research Program.[68] The report included a thorough review of the findings of research studies conducted by others, the findings of a research study conducted by the authors that investigated 42 unsignalized crosswalks in cities across the United States, and recommendations for both design guidelines and changes to the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD).

The researchers discussed the classic San Diego study from the early 1970s, which found two to three times as many crashes occurred at marked versus unmarked unsignalized crossings, and which has long been interpreted by engineers as providing evidence that unsignalized crossings should not be marked.[69] One problem with the San Diego study is that it limited the scope to unsignalized crossings with or without pavement markings. In addition, it does not reflect more recent installations of multiple crosswalk treatments or alternative crosswalk treatments such as flashing beacons.

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[68] **Fitzpatrick, Kay**, Shawn Turner, Marcus Brewer, Paul Carloson, Brooke Ullman, Nada Trout, Eun Sug Park, and Jeff Whitacre. 2006. Improving Pedestrian Safety at Unsignalized Crossings. TCRP Report 112, NCHRP Report 562, Transportation Research Board, Washington, D.C.

[69] As quoted in Fitzpatrick et al., 2006:
Herms, B. F. "Pedestrian Crosswalk Study: Accidents in Painted and Unpainted Crosswalks." Highway Research Record 406, Highway Research Board, National Research Council, Washington, DC, 1972, pp. 1-14.

From their own empirical study of crosswalks, which included unsignalized crosswalks having a range of treatments, Fitzpatrick et al. determined that different crosswalk markings were associated with different rates of motorist compliance at unsignalized crossings. In particular, they found that crossing treatments that included a red signal or beacon had 95% motorist compliance rates, even when they were located mid-block. This finding is of particular interest, because most of the crosswalks they studied with this treatment were high-speed arterial streets carrying high traffic volumes. In addition, they found high rates of motorist compliance at unsignalized crossings that had either in-street crossing signs or hand-held crossing flags that pedestrians could use when crossing (rates of 87 and 65 percent, respectively). However, all the crossings studied with these features were on relatively low-volume, low-speed, two-lane highways, so their effectiveness on other highway types was not established. In fact, an experiment with hand-held flags in Berkeley, California, was considered a failure by the city and discontinued after two years.[70] In the end, the researchers concluded that along with the type of crosswalk treatment, the number of lanes a pedestrian needed to cross and the posted speed limit were the significant factors that influenced motorist compliance.

Another comprehensive study by **Zegeer et al. (2005)** compared the safety of unmarked and marked crosswalks, and determined that the effectiveness of various crosswalk treatments depends heavily upon the ADT of the roadway.[71] After reviewing 1000 sites each of marked and unmarked crosswalks at uncontrolled locations (no traffic signal or stop sign), the researchers found that marked and unmarked crosswalks, when used in isolation, performed statistically similarly on all two-lane roads and multilane roads with ADT of about 10,000 or less. However, for multilane roads with marked crosswalks and ADT greater than 10,000, the data showed that pedestrian crash rates increased as ADT increased. In contrast, the data showed that pedestrian crash rates on multilane roads with unmarked crosswalks and ADT greater than 10,000 increased only slightly. These findings suggest that marked crossings may lend a false sense of security to

[70] Tri Valley Herald. Berkeley removes remaining pedestrian safety flags. March 13, 2004.
[71] **Zegeer, Charles V.**, J. Richard Stewart, Herman H. Huang, Peter A. Lagerwey, John Feaganes, and B.J. Campbell. 2005. Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommendations Guidelines.

pedestrians when crossing multilane roads with high traffic, and that the crossings should therefore be supplemented with other treatments on multilane roads with ADT of 10,000+.

The data also suggested that raised medians and raised crossing islands significantly lowered pedestrian crash rates on multilane roadways. However, the findings indicated that neither non-raised, painted medians, nor two-way, left-turn lanes (TWLTLs), offered significant safety benefits when compared to roadways without any type of median; i.e., painted medians were not found to confer the same safety benefits as physical medians in the roadway.

The researchers concluded that marked crosswalks should not be used in the following situations without supplementary traffic calming, signalization, or other crossing improvements:

- Where speed limits exceed 40 mph
- On two-lane roadways with ADT > 12,000
- On multilane roadways without a raised median/crossing island and an ADT > 9,000
- On multilane roadways with a raised median/crossing island and an ADT > 15,000

To better understand Zeeger et al.'s findings, **Ragland and Mitman (2007)** examined driver and pedestrian understanding and behavior at marked and unmarked crosswalks in California.[72] The results of the study indicated that drivers are less likely to yield at unmarked crosswalks, even though required by law, probably due to misinformation about pedestrian right-of-way priority. However, the lower rate of yielding is associated with fewer collisions, likely a result of greater pedestrian care to balance the reduced driver care. Ironically, intersections with 2+ lanes in each direction and marked crosswalks are associated with more yielding but also a greater risk of collision, due to multiple-threat crashes that occur when one driver yields but the driver in the next lane does not. This research underscores the need for multiple safety interventions when using a marked crosswalk.

[72] **Ragland, David R.** and Meghan Fehlig Mitman. 2007. Driver/Pedestrian Understanding and Behavior at Marked and Unmarked Crosswalks. UC Berkeley Traffic Safety Center.

In a focus group survey conducted in conjunction with this study, the researchers found that participants held strong opinions on what additional measures they would like to see with the crosswalk. The results follow in Table 12:

Table 12. Engineering Solutions and Associated Focus Group Support

Design Solution	Individuals in Favor
Yield Sign	16/23 (70%)
Stenciled Crosswalk	15/23 (65%)
Raised Crosswalk	3/23 (13%)
Bulb-out	18/55 (33%)
Flashing Beacon	30/55 (55%)
In-Pavement Lighting	47/55 (85%)
Lane Reduction/Road Diet	14/32 (44%)
Countdown Signal Crossing	38/44 (86%)

These results do not necessarily conform with the most effective traffic calming treatments; for example, only 13% prefer raised crosswalks, yet raised crosswalks have been found to improve safety, particularly when used in conjunction with complimentary treatments. However, the strong preference for in-pavement lighting is matched well with successful performance, as this lighting has been associated with increased driver yielding behavior. The difference between popular opinion and statistical reality is likely due in part to people's perceptions of safety, and can prove a challenge for transportation engineers and designers in communities. However, as researchers continue to develop techniques that both confer both actual and perceived safety to the user, it is possible that this difference will minimize or disappear.

Pedestrian Warning Lights at Crosswalks

In-pavement warning lights take two basic forms, those that are activated when a pedestrian pushes a button ("active"), and those that activate automatically in the presence of a pedestrian ("passive"). "Passive" warning lights are generally activated when pedestrians pass through and break a laser beam that is typically routed through a pair of bollards mounted at the intersection of the sidewalk and the crosswalk, although some systems work via video. Research on both active and passive warning lights is reviewed in this section.

Godfrey and Mazzella (1997) investigated the safety effects of the pedestrian activated in-roadway warning lights that had been installed at two crosswalks on urban arterial streets in Kirkland, Washington.[73] The data indicated that yielding improvement increased from 16% to 100% in one location, and the *lowest* yielding rate was 92% after installation. In addition, the distance from the crosswalk at which drivers began to brake increased in every location when lights were activated. Field observations also indicated that the presence of the warning lights did not seem to give pedestrians a false sense of crossing security; i.e., they still exhibited caution when crossing the street.

In a related study, **Van Houten et al (1998)** investigated the effects of adding various warning signs to crosswalks on a divided six-lane arterial street in Dartmouth, Nova Scotia, where pedestrian activated in-roadway warning lights were already installed.[74] One crosswalk studied was at an intersection, while the other was mid-block. The first intervention involved adding an illuminated pictograph sign near the crosswalk with the standard pedestrian symbol on it. The second involved erecting signs 50 meters (164 feet) before the crosswalk that displayed the pedestrian symbol and requested motorists to yield when the beacons were flashing. From field observations of roughly 100 pedestrian crossings, the researchers found that with the addition of either the illuminated pictograph or the yield sign, driver yielding increased by approximately 10% (from 67% to 77%). With the addition of both the pictograph and the yield sign, driver yielding increased 20%, to approximately 87%.

Whitlock and Weinberger Transportation, Inc. (1998) evaluated the performance of in-pavement crosswalk flashers on urban arterials having an ADT of 16,000–55,000 in Santa Rosa, California.[75] Data collection was done for pedestrian users of the crosswalk and drivers who crossed it. Driver reaction observations were conducted for two conditions: 1) when the driver first noticed a pedestrian who appeared to be staged to cross the intersection; and 2) when a

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[73] **Godfrey, David** and Tony Mazzella. 2000. Success in Redesigning Main Streets for Pedestrians. City of Kirkland, Washington.

[74] **Van Houten, Ron**, Keenan Healey, J.E. Louis Malenfant, and Richard Retting. 1998. Use of Signs and Symbols To Increase the Efficacy of Pedestrian-Activated Flashing Beacons at Crosswalks Transportation Research Board of the National Academies. ISSN0361-1981. Volume 1636.

[75] **Whitlock and Weinberger Transportation , Inc. 1998**. An Evaluation of a Crosswalk Warning System Utilizing In-Pavement Flashing Lights. Report published April 10, 1998.

pedestrian stepped into the roadway. Information was collected on approach speed, travel time/deceleration, braking distance, and driver reaction (did they stop, yield, not stop). Interviews of drivers who had crossed the crosswalks were also conducted. These interviews were aimed at determining driver awareness of the crosswalk and warning treatments. As well, pedestrian users of the crosswalks were interviewed for their perceptions of the crossing treatment. Follow up studies were conducted two years after the initial study to gauge the longevity of the effects from the crosswalk treatment. The key finding was that pavement flashers at uncontrolled intersections have a positive effect in enhancing driver awareness of crosswalks, especially during darkness, fog, rain, and other adverse weather conditions, although the long-term effects degrade slightly over time. The in-pavement flashers worked best in locations where there was moderate pedestrian traffic, defined as approximately 100 pedestrians a day. The pedestrian surveys indicated that automatic activation devices are better for pedestrians as they do not cause confusion or require push-button activation.

Hakkert et al. (2002) conducted a before and after study to investigate the safety effects of adding different types of passive in-pavement warning lights to marked crosswalks at unsignalized locations.[76] The research involved the study of four uncontrolled mid-block crosswalks along two- and three-lane arterial streets in central areas of two Israeli cities, where driving speeds ranged from 18–25 mph, vehicle volumes ranged from 600–1700 per hour, and pedestrian crossing volumes ranged from 30–500 pedestrians per hour. Two of the crosswalks received an Active Road Marking System for Road Safety (ARMS) warning light system that was activated when a pedestrian was detected entering the crosswalk. The other two received a Hercules™ warning light system that was activated twice, once when a pedestrian was detected entering the crosswalk, and again when the pedestrian left it. Three rounds of observations were conducted: before installation, several weeks after installation, and several months after installation. Observations were conducted in 6–8 hour intervals on weekdays at the four test locations. The researchers found that both crosswalks with the ARMS system experienced decreases in free and crosswalk-adjacent vehicle speeds after implementation, whereas data from

[76] **Hakkert, A. Shalom**, Victoria Gitelman, and Eliah Ben-Shabat. 2002. An evaluation of crosswalk warning systems: effects on pedestrian and vehicle behaviour. Transportation Research Institute, Technion—Israel Institute of Technology, Technion City.

the two crosswalks using Hercules™ showed mixed results. At one of the ARMS crosswalks, pedestrians previously ignored spatial crosswalk boundaries 50% of time, while after installation this behavior dropped to 10%.

Perhaps most importantly, the rate of vehicle and pedestrian conflicts (defined as an abrupt change of course or speed by one of them in order to avoid a collision) was reduced to less than 1% for all four sites. The researchers concluded that the installation of a passively activated in-pavement warning light system at unsignalized marked crossing locations can increase safety. These systems seem to be particularly suitable where average vehicle speeds are over 18 mph, there is "intensive pedestrian flow" (defined by the 1994 Manual on Traffic Engineering as over 160 pedestrians per hour, across eight hours of observations), and the rate of drivers giving way to pedestrians is low.

These conclusions are corroborated by a study done by Hughes and Huang (2001), which found a significant reduction in both vehicle-pedestrian conflicts and the likelihood of inappropriate pedestrian crossings when an automated pedestrian detection system was used in conjunction with traditional pedestrian call devices.[77] In addition, fewer pedestrian crossing behaviors indicating fear or excess caution (running, hesitation, or crossing abortion) were observed.

Using a before and after study approach, **Rousseau et al. (2004)** investigated the effects of a passive in-pavement pedestrian warning light system installed at the crosswalk of an uncontrolled intersection on pedestrian and driver behavior.[78] The two-lane urban arterial highway in Rockville, Maryland, had parking lanes on both sides and a 25 mph speed limit. The in-roadway lighting system included two passive detection bollards on the edge of the curb at either end of the crosswalk, seven lights on each side of the crosswalk, and a series of four lights in the center line either side of the crosswalk, spaced about 15 feet apart, which lit up in

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[77] As quoted in Hakkert, 2002:
Hughes, Ronald and Herman Huang. 2001. Evaluation of Automated Pedestrian Detection at Signalized Intersections. FHWA-RD-00-097.

[78] **Rousseau, Gabriel**, Sheryl Miller Tucker and Ann Do. 2004. The Effects on Safety of In-Roadway Warning Lights at Crosswalks: Novelty or Longevity? 2004 Annual Meeting and Exhibit.. Institute of Transportation Engineers.

sequence to draw attention to the crosswalk. The researchers observed 744 pedestrian crossings, 368 before the installation of the in-roadway warning light system and 376 after the installation.

The key finding regarding driver behavior was that significantly more vehicles yielded for pedestrians after the lights were installed compared to the before condition. During the 'after' data collection period, the lighting system temporarily malfunctioned for one side, resulting in the lights not activating in one direction. However, the fact that the drivers yielded more during the malfunction period than the before period suggested to the researchers that driver learning had occurred. The researchers did not measure the driver speeds, so the impact of the warning lights on speed could not be determined. A key finding regarding pedestrian behavior was that the assertiveness of pedestrian crossings changed neither positively nor negatively, potentially signaling that the treatment did not lead to a false sense of security. However, in this case, the in-pavement lighting had only minor impact on pedestrian choice to use the crosswalk: before installation, the crosswalk usage was 72.8%, while after installation the usage was measured at 75%. The authors surmised that the pedestrians often chose to cross outside rather than inside of the crosswalk for convenience and reduced distance to destinations on the other side of the road.

In order to improve the effectiveness of in-roadway warning lights, the researchers suggested that the systems be installed with both passive and active actuation, to reduce the risk of malfunction. In addition, they suggested that it may be beneficial to place the detection bollards further apart than the width of the crosswalk, as this study found that a number of pedestrians entered the crosswalk just outside the passive detection system and therefore did not trigger the lights. Overall, however, the lighting system appeared to successfully affect driver-yielding behavior.

Abdelghany (2005) examined literature on in-pavement and overhead pedestrian warning light systems to determine which system was more effective.[79] The various studies examined the two warning lights systems at uncontrolled crosswalks to determine their effects on traffic speeds, motorist/pedestrian interaction, driver yielding behavior, and overall pedestrian safety, and

[79] **Abdelghany, Ahmed**. 2005. Above-Ground Actuated Yellow Crosswalk Lights at Uncontrolled Pedestrian Crossings. Alaska Department of Transportation & Public Facilities.

compared this data to findings about in-pavement lights. Abdelghany found that the above-ground flashing lights had little impact on reducing speeds near crosswalks (2-3 mph), and that they were associated with a 5% increase in pedestrian activity post-installation. Mid-block flashing lights of both types were found to be successful in reducing conflicts between vehicles and pedestrians (66% total reduction). The research also showed that embedded flashing lights are generally more effective than the above-ground lights, and tend to remain effective for longer periods of time.

The findings from the research reviewed in this section seem to overwhelmingly suggest that in-roadway warning lights contribute to increased driver yielding and pedestrian compliance, and reduced driver speed. This combination of factors should lead to increased traffic safety for all involved, and could be a reliable way to encourage appropriate pedestrian and driver behavior along arterials.

Other Crosswalk Signage Treatments

Huang et al. (2000) studied the effect on pedestrian safety of adding additional traffic calming elements to a marked crosswalk at an unsignalized location.[80] The researchers looked at a total of 11 crosswalks on arterial streets in various cities across the United States—Seattle, Washington; Portland, Oregon; Tucson, Arizona; and several cities in New York State. The streets represented a considerable variety of arterial street conditions, as shown in Table 13.

The researchers found that pedestrian confidence—measured as less running, hesitating, or aborting the crossing when faced with oncoming traffic—improved significantly at the 1 overhead location, 2 of the 7 locations with the pedestrian cone and regulatory sign, and 2 of the 3 pedestrian regulatory sign locations. In addition, they found that driver yielding behavior was significantly affected at the 1 location with the overhead crosswalk sign and 4 of the 7 locations with both the pedestrian safety cone and pedestrian regulatory sign.

[80] **Huang, Herman**, Charles Zegeer, and Richard Nassi. 2000. Effects of Innovative Pedestrian Signs at Unsignalized Locations. *Transportation Research Record*. 1705.

However, driver-yielding behavior was not affected by the pedestrian regulatory signs at any of the three Tucson locations. It should be noted that the three Tucson streets all had 4 or 6 travel lanes, were the only streets in the study without on-street parking, and carried the highest ADT of the streets studied (22,000, 32,100, and 61,700). These results generally corroborate the conclusions of other research studies – that multiple traffic calming features are more effective than single features. However, the Tucson results suggest that the installation of just two traffic calming features on wide and fast arterials with relatively high traffic volumes may not result in any traffic calming effect—at least not with the two types tested in this study.

Table 13. Characteristics of Study Locations

TREATMENT	CITY AND LOCATION M = MIDBLOCK I = INTERSECTION	NUMBER OF LANES	SPEED LIMIT	ADT	ON-STREET PARKING
Overhead crosswalk sign	SEATTLE, WA Western Ave at Bell St (I)	One-way street 2 lanes, with a raised divider	48 km/h (30 mi/h)	6,800	2 sides
Pedestrian safety cone	ALBANY, NY Pearl St at Steuben St (I)	2 + two-way left-turn lane	48 km/h (30 mi/h)	9,000	2 sides
Pedestrian safety cone	BALLSTON SPA, NY Milton Ave at Van Buren St (I)	2	48 km/h (30 mi/h)	15,500	2 sides
Pedestrian safety cone	PORT JEFFERSON, NY Main St at Arden Pl (I)	2			2 sides
Pedestrian safety cone	SARATOGA SPRINGS, NY Route 9 at Caroline St (I)	4	48 km/h (30 mi/h)	13,500	2 sides
Pedestrian safety cone	SCHENECTADY, NY State St between Furman St and Division St (M)	2	48 km/h (30 mi/h)	14,000	2 sides
Pedestrian safety cone	TROY, NY 15th St at RPI Union (M)	2	48 km/h (30 mi/h)	7,200	2 sides
Pedestrian safety cone	PORTLAND, OR SE Division St at SE 30th Ave (I)	2	40 km/h (25 mi/h)	13,700	2 sides

Table 13. Characteristics (continued)

Pedestrian regulatory sign	TUCSON, AZ Euclid Ave at 7th St (I)	4 + refuge island	48 km/h (30 mi/h)	22,000	No
Pedestrian regulatory sign	TUCSON, AZ St. Mary's Rd at Melrose Ave (I)	4 + two-way left-turn lane	56 km/h (35 mi/h)	32,100	No
Pedestrian regulatory sign	TUCSON, AZ Speedway Blvd at Plumer Ave (I)	6 + refuge island	64 km/h (40 mi/h)	61,700	No

In an innovative study, **Nasar (2003)** sought to determine the effectiveness of hand-held written signs in increasing the proportion of drivers stopping for pedestrians at two consecutive crosswalks on an urban arterial near Ohio State University.[81] The research involved field observations of driver and pedestrian behavior during three consecutive weeks: one week before the signs were introduced, one week while they were used, and one week after they were no longer being used. During the middle week, in addition to observing behavior the researchers actively intervened at the first crosswalk in response to driver behavior. If a driver stopped for a pedestrian crossing the street, the observer held up a green sign that said, "Thanks for stopping." If a driver did not stop for a pedestrian, a different observer down the street held up a pink sign that said, "Please stop next time." No interventions were made at the downstream crosswalk, but observations of driver and behavior were conducted there to investigate driver learning.

The researchers discovered that during the week when the signs were shown, the number of drivers stopping at the treated crosswalk increased almost 5% from the baseline conditions (from 46% to 50.9%), and the number of drivers stopping at the untreated, downstream crosswalk increased by 6% (from 38% to 44%). The results suggest that hand-held signs may encourage drivers to stop for pedestrians, leading to the idea that a concerned community might be able to institute a local, site-specific "driver education" program using such techniques. More generally, the research suggests that "social learning" about the need for traffic calming can occur through programs that encourage pedestrian awareness, rather than just through the implementation of

[81] **Nasar, Jack**. 2003. Prompting Drivers to Stop for Crossing Pedestrians. *Transportation Research Part F* 6:175–182.

physical solutions. Perhaps signage that requires "driver eye-contact" before crossing or some other innovative solution may work equally well compared to traffic calming and warning lights. Future research exploring social/interactive cues between pedestrians and drivers could lead to improved driver awareness and encourage driver yielding.

Right Turn Conflicts

A research focus related to pedestrian safety at intersections concerns conflicts with right-turning vehicles. **Cleven and Blomberg (2007)** recently completed a compendium of National Highway Traffic Safety Administration (NHTSA) research projects that identifies, among other things, studies that point to changes in traffic safety that have occurred in the United States since 1969 as a result of changes to federal or state transportation policies.[82] The study cites a compendium by Preusser et al. (1981) that found pedestrian and bicycle crashes involving a motorist making a right turn at a signalized intersection increased significantly at studied intersections following the adoption of right-turn-on-red (RTOR) legislation. A 1994 follow-up report prepared by others found that indeed each year a number of pedestrian deaths and injuries throughout the country are caused by RTOR crashes, but the authors dismissed these crashes as insignificant to the overall traffic safety picture. In recent years, some researchers have investigated the effectiveness of measures intended to reduce the pedestrian and vehicle conflicts resulting from RTOR policies.

Johnson et al. (2005) studied four intersections in Emeryville, California, in order to determine how safe they were for pedestrians and bicyclists.[83] The intersections were all on urban arterial streets that handled peak hour vehicle volumes ranging from 2,122–4,310, and one was located at a freeway on-ramp. Using mixed methods that included field observations of driver and pedestrian behavior at the intersections, surveys of pedestrians and bicyclists, recording of concerns expressed at community meetings, and analysis of crash data, the researchers identified the primary concerns relative to intersection safety. Among other things, vehicle right turns were problematic for pedestrians in three circumstances—RTOR, right turns on green, and right turns

[82] **Cleven, Arlene M.** and Richard D. Blomberg. 2007. A Compendium of NHTSA Pedestrian and Bicyclist Research Projects: 1969-2007. U.S. DOT – National Highway Traffic Safety Administration.
[83] **Johnson, Emily S.**, Jill Cooper, David R. Ragland, and Terri O'Conner. 2005. Pedestrian and Bicycle Safety Evaluation for the City of Emeryville at Four Intersections. Institute of Transportation Studies. UC Berkeley Traffic Safety Center.

at unsignalized crossings—often due to drivers looking only left, towards approaching traffic, or accelerating onto the freeway onramp. These findings suggest some type of intervention is necessary to ensure pedestrian safety over vehicle right of way. One possibility is a combination of a leading pedestrian interval, allowing pedestrians to cross without threat of vehicle conflict, and a prohibition of the RTOR maneuver.

This same study revealed that a long crossing distance combined with inadequate signal crossing time and a lack of refuges was a problem for many intersections. Of ten crossings, only four provided enough time for someone to cross walking at 4 ft/sec, and only two provided enough time for someone to cross at 2.5 ft/sec, the commonly cited crossing speed for slower-moving pedestrians such as seniors, parents with strollers, or disabled persons. As well, excessive vehicle speeds seemed to contribute to a hostile pedestrian environment—exaggerated in this case by wide lanes, large intersections, and wide curb radii, as did the absence of crosswalks on all legs of the intersection. These findings suggest multiple interventions needed at these sites: extended crossing times for pedestrians, slowed vehicle speeds through traffic calming measures, and the installation of crosswalks where they were previously absent.

Seeking to find out if the implementation of Leading Pedestrian Intervals (LPI's) increased pedestrian safety where RTOR vehicle movements were allowed at signalized intersections, **King (2000)** studied crash rates and crash severity data for 26 intersections in New York City where LPI's were in place and compared them with accident data for similar intersections without LPI's.[84] Analyzing approximately 5 years each of before and after data for the intersections with LPI's, he found both the number of vehicle/pedestrian crashes and crash severity were reduced when intersections had LPI's. On average, the installation of an LPI led to a 12% reduction in pedestrian/vehicle crashes and a 55% reduction in crash severity. The intersections studied had LPI lengths ranging from 5–11 seconds, and perhaps counter-intuitively, some of the shorter lengths resulted in greater crash reductions. For example, a 5-second LPI on 1st Avenue was associated with 13 fewer vehicle/pedestrian crashes than its control site (20 vs. 33) and a 6-second LPI on 62nd Street was associated with 39 fewer crashes

[84] **King, Michael R.** 2000. Calming New York Intersections. Transportation Research Circular No. 501.

than its control site (13 vs. 52), while an 11-second LPI on Madison Avenue was associated with 4 fewer crashes than its control site (17 vs. 21).

Because the research study did not control for LPI length relative to vehicle volumes, pedestrian volumes, or crossing distance, it does not provide clear evidence of what length of LPI provides the highest level of crash reductions. Nonetheless, the research strongly implies that LPI's increase pedestrian safety. The findings on reduced injury severity are somewhat opaque because the research used the New York State Department of Transportation's CASIUS severity mapping program, based on the cost of the crash to the public, to evaluate the severity of accidents post-LPI installation, and the values assigned to different types of injuries or property damage are not fully articulated.

A more common approach to increasing pedestrian safety at signalized intersections is the installation of pedestrian countdown signals. **Eccles et al. (2004)** evaluated the effects of such signals on pedestrian and driver behavior by studying five intersections with countdown signals located along urban arterial highways in Montgomery County, Maryland.[85] After observing pedestrian and driver behavior before and after the signals were installed, the researchers concluded that the pedestrian countdown signals did not have negative effects on either driver or pedestrian behavior. Importantly, the presence of a pedestrian countdown signal had no clear effect (positive or negative) on the speed of a driver approaching the intersection. Moreover, the presence of pedestrian countdown signals had a marked positive effect on pedestrian behavior. Of the 20 crosswalks studied (each intersection had 4 crosswalks), 6 experienced significant increases in the number of pedestrians entering the crosswalk on the "walk phase," while 2 experienced significant decreases. In addition, 3 of the 5 intersections experienced significant decreases in the number of pedestrians remaining in the intersection after the light had turned red.

[85] **Eccles, Kimberly A.**, Ruihua Tao, and Bruce C. Mangum. 2004. Evaluation of Pedestrian Countdown Signals in Montgomery County, Maryland.

Summary of Key Research Findings

The following is a summary of the key findings on the research related to corridor roadside design and pedestrian safety:

The presence of pedestrian refuge islands (i.e. center medians), roadside trees, highly visible crosswalks, and intersection traffic controls that include pedestrian priority phasing can, according to the research cited above, all contribute to increased pedestrian safety. Generalizing from the research the specific and quantifiable impacts that particular roadside design elements will have on pedestrian safety on any given highway is, however, difficult.

As the many research studies show, pedestrian safety concerns on arterials, particularly those in urban environments, are a major subject of study. The studies show that there are many effective ways to decrease vehicular speed, to decrease crashes between vehicles and pedestrians, and to decrease serious injury or death. At the same time, only one study involved trees, and it concluded that trees were very influential in reducing perceived roadway widths and, in likely consequence, reducing driving speed and accidents. An overall conclusion for this section, then, is that there is little existing research on the safety effects of roadside planting or design elements on pedestrian safety.

The following findings from the research are somewhat less directly related to corridor roadside design, as they are more concerned with roadbed and intersection design:

- Higher vehicle ADT along a corridor seems associated with higher rates of pedestrian accidents.
- Collisions between vehicles and pedestrians decrease as pedestrian volumes increase.
- Higher vehicle speeds are associated with more serious pedestrian injuries.
- 85% of pedestrian fatalities occur on non-local streets.
- Traffic calming techniques, particularly speed humps, are effective in slowing driver speeds. Combinations of traffic calming techniques work better than single techniques.
- Narrower roadways seem associated with slower speeds and fewer collisions between vehicles and pedestrians.
- On-street parking, whether parallel or angled, calms vehicle traffic.

- At crosswalks, pedestrians seem to pay more attention than drivers.
- Pedestrian activated warning lights at mid-block crosswalks are associated with more driver-yielding compliance and lower collision rates.
- At intersections, right-turns on red and long crossings cause problems for pedestrians, whereas leading pedestrian indicators are effective at creating greater pedestrian safety.

Future Research Needs

- Additional research that would be helpful would be numerous case studies of differently designed highways with known high or low accidents rates, that focus on pinpointing causalities in each particular location. Once a considerable number of case studies have been done, generalizations might be more easily achieved.
- An example of additional possible research would be the impact on pedestrian safety of on-street parking along urban arterials – does it measurably slow traffic?
- Comparative case studies of pedestrian safety along streets with trees and other landscape materials along street edges (at curbs, along planting strips) and streets without such plantings.
- Case studies that explore impacts, if any, of dense trees and plant materials near intersections and at mid-block crossings, as compared to no trees or planting at these areas.
- Studies of walking along rural arterials with and without regular trees, and the impacts on both walkers' perceptions of safety and actual numbers and severity of vehicle/pedestrian crashes.

Bicyclist Safety

Bicyclist safety seems to have inspired much less research than pedestrian safety, at least in the United States. This is likely due in part to the lower overall numbers of bicyclists in the United States (approximately 1% average mode share), and in part to the cost and difficulty of data collection. In addition, the traffic safety statistics for bicyclists often paint a picture that

bicycling is less dangerous than walking, although this is due in part to overall lower exposure numbers. However, travel by bicycle is likely to grow, particularly as energy and health concerns come more to the forefront of urban and suburban life. Several communities in the U.S. are currently experimenting with new facility designs, such as bike boxes, painted lanes, and cycle tracks – techniques common in many European countries that have a generally high bicycling mode share (x > 10%). These experiments aim to hone these techniques to be appropriate in a U.S. setting, and may eventually encourage a higher bicycling mode share in the U.S.

The research that has been done on bicyclist safety has focused on two main areas: on-street bicycle lanes and on-street vehicle parking. Because on-street parking can present a significant traffic safety challenge for bicyclists using bicycle lanes, these two areas of research have been presented together.

Bicycle Lanes and On-Street Vehicle Parking

Some researchers have looked at the effects of different types of bicycle lanes on driver and bicyclist behavior. **Hunter (1998)** conducted a before and after study of a two-lane rural highway in Florida, a one mile section of which contained red painted shoulders that served as bicycle lanes.[86] The highway had 9.5-foot travel lanes, a posted speed limit of 35 mph, and carried approximately 1,700 AADT; paved shoulders on each side were 3 feet wide. The red paint used was a type used for tennis courts that creates a non-slippery surface. Speed data was collected using pneumatic tubes and digital counters both before and after the red shoulders were painted, at locations with and without the paint. Video cameras installed at four locations—three with red shoulders, one without—collected data on driver and bicyclist behavior both before and after the shoulders were painted. In all, video footage was obtained of 757 bicyclists (approximately 66% of whom where male), and was analyzed to determine whether or not bicyclists used the shoulders, the lateral positioning of bicyclists being passed by motor vehicles, and the severity and amount of vehicular encroachment into oncoming traffic while passing a bicyclist. In addition, bicyclists were surveyed to solicit their feedback regarding the shoulders. Of 125 questionnaires handed out, 92 were received back, a response rate of 73.6%.

[86] **Hunter, William W.** 1998. An Evaluation of Red Shoulders as a Bicycle and Pedestrian Facility. University of North Carolina. Highway Safety Research Center.

The key finding regarding driver behavior concerned passing behavior. The level of vehicle encroachment into the oncoming lane when passing a cyclist was measured at one of the red shoulder locations and at the unpainted shoulder location. At the red shoulder location, vehicle encroachment into the oncoming lanes when passing a bicyclist was distributed evenly between minor, moderate, and severe levels (a severe encroachment was defined as the passing car traveling over halfway into the other lane to avoid the cyclist), but there were also numerous occasions where bicyclists were passed without encroachment. At the location without a red shoulder, vehicle encroachments were nearly all severe, indicating that drivers passed cyclists with more space. Although much more space was given to the cyclists, the greater rate of encroachment at times caused serious conflict with oncoming traffic (conflict was defined as a vehicle needing to suddenly change speed or alter course), which could ultimately compromise traffic safety for all on the roadway.

The key finding from the video analysis regarding bicyclist behavior was that nearly 80% of the cyclists used the red shoulders the entire length they were available, 14% never used them, and about 6% used them part-time; most of the non-users were in groups where cycling was done two abreast. In addition, between the painted shoulder conditions and the unpainted condition, there were no significant differences in how close to the edge of the adjacent travel lane bicyclists rode.

Analysis of the survey results showed that bicyclists perceived the red shoulders positively. Eighty percent of the respondents didn't think that the red shoulders had encouraged drivers to increase their speed, and just over 13% thought that the red shoulders had caused drivers to reduce their speed. In all, 79% of the respondents reported feeling safer with the painted shoulders. Interestingly, and directly contrary to actual conditions, 86% of the surveyed bicyclists perceived that where a red shoulder existed there was more space between bicyclists and passing vehicles than where the shoulder was unpainted, while the rest perceived no difference between the two conditions. These findings suggest that this type of treatment could be well-received by cyclists in other areas, and could contribute to their riding enjoyment without compromising their safety.

Another study by **Hunter and Stewart (1999)** evaluated the safety effects of striped bicycle lanes along arterial streets with on-street parking.[87] This research was conducted on two 4-lane urban arterials in Florida, one in Fort Lauderdale and the other in Hollywood; the details of the study streets are shown in Table 14. The researchers used video cameras to record driver and pedestrian behavior at selected locations on each street; image analysis software (SigmaScan Pro 4.0) was used to determine positioning and spacing data, using the width of the bike lane as the calibration measure.

Table 14. Study Street Characteristics

City	AADT	Travel Lane Width	Bike Lane Width	Parking Turnover Rate	Number of Cyclists Observed
Ft. Lauderdale	28,000	10.5 feet	4.5 feet	111 vehicles/hour	321
Hollywood	12,700	12 feet	5 feet	11 vehicles/hour	317

The key finding was that there were few conflicts between vehicles and bicyclists at either location: 2.5 conflicts per 100 bicycles in Ft. Lauderdale and 1.6 per 100 in Hollywood (8 and 5 total, respectively). On the street in Fort Lauderdale, 6 of the 8 conflicts involved motorists attempting to park (drivers were often observed waiting in the bicycle lane for a parking space to open, blocking the lane from cyclists). On the street in Hollywood, conflicts were mainly caused by vehicles turning onto or off of cross streets. When conflicts occurred, bicyclists routinely adjusted their behavior to avoid collisions.

Analysis of bicycle positioning revealed that on both streets, cyclists generally rode in the center of the bike lane; however where cars were parked particularly close to the curb, cyclists tended to ride a bit off-center and further away from passing traffic. Although the bike lane on the Hollywood street was six-inches wider, the cyclists tended to ride farther from the outside edge (closer to parked cars) when being passed than those on the Fort Lauderdale street. The researchers suggest that this could be attributed to bicyclists perceiving fewer potential conflicts

[87] **Hunter, William W.** and J. Richard Stewart. 1999. An Evaluation of Bike Lanes Adjacent to Motor Vehicle Parking. University of North Carolina. Highway Research Center.

with parked cars given the significantly lower parking turnover rate. The mean passing distance calculated for vehicles was 1.75 feet less on the Fort Lauderdale street than on the Hollywood street, approximately the difference between the width of the two streets' vehicle travel lanes. On both streets, the typical minimum passing distance was greater than 3 feet, a widely accepted standard. A limitation of the research is that vehicle speed was not reported, so the applicability of the findings to highways with different speeds is uncertain. In addition, it is unclear from the research what effect bike lanes have on drivers' awareness of passing cyclists when the drivers are exiting their parked cars.

Summary of Key Research Findings

The following is a summary of the key findings on the research related to corridor roadside design and bicyclist safety:

- Red-painted bicycle lanes placed on the roadway shoulder are positively perceived by bicyclists, who tend to ride in them when they are available and feel that they increase safety. As well, these painted bicycle lanes may lead to overall roadway safety because drivers passing bicyclists riding in a painted lane did so with less encroachment into the opposite direction travel lane.
- Along 4-lane arterial streets with on-street parking, there does not seem to be a conflict between striped bicycle lanes and on-street parking, at least not where the bicycle lanes are 4.5–5 feet wide and ADT is below 28,000.

Future Research Needs

In terms of roadside design impacts of bicyclist safety, it would perhaps be best to direct early research to places where innovative roadway bicycle facilities have been implemented on a wide scale; in the United States, this would be places like Portland, Oregon, and New York City, New York; in Europe, this would be places like Paris, France, Copenhagen, Denmark, and Amsterdam, The Netherlands. Examples of future research include:

- Understanding the impacts of painted bicycle lanes on arterial streets, such as those in Portland, Oregon, including effects on traffic safety and absolute numbers of bicyclists.
- Understanding the effects of painted bicycle boxes, such as those in Portland, Oregon, including effects on traffic safety and absolute numbers of bicyclists.

- Understanding the impacts of separated cycle tracks, such as the recent installations in Manhattan, New York, and Boston, Massachusetts, including effects on traffic safety and absolute numbers of bicyclists. This research should be supplemented by research from Copenhagen, Denmark.
- Understanding the impacts of separate bicycle traffic signals and phases, currently in use in Portland, Oregon, including effects on traffic safety and absolute numbers of bicyclists. This research should be supplemented by research from Copenhagen, Denmark, and Amsterdam, The Netherlands.
- Understanding the effects of "bicycle boulevards", such as those in Portland, Oregon, and Berkeley, California, including effects on traffic safety and absolute numbers of bicyclists.
- Examining the effects of "stop-as-yield" rules in the state of Idaho and some cities around the U.S., including impacts on traffic safety and user behavior.
- Examining the safety effects of bicycle-oriented lighting along bicycle priority routes.

CHAPTER III: HEALTH EFFECTS

Public health concerns regarding traffic safety have long been associated with highways and other roadways, but chronic disease and psychological health concerns have been less directly connected to transportation infrastructure. However, research in the last few decades has broadened the range of health effects impacted by travel and the associated infrastructure. This chapter examines the impact of highways and arterials, in particular their associated roadway design elements, on public health. The chapter is divided between research on physical and psychological health. Physical health is examined in three sub-sections: walkability, bikability, and physical activity and the built environment. The research has been thus sub-divided to distinguish between the literature that focuses specifically on the design characteristics of walkable or bikable neighborhoods and communities, and that which attempts to understand and quantify the association between certain characteristics of the built environment and the propensity to walk or bike for utilitarian or recreational purposes. Psychological health is addressed in the final sub-section through literature that explores the affects of certain roadway design features on various emotional and mental states of being.

A note about the content of this chapter: although it is undeniable that the typical U.S. pattern of sprawling development and separated land use makes it difficult for many to walk and bicycle to and from various origins and destinations, this review does not delve into research on land use and development patterns and their effects on travel choices. For more information about this subject, the authors recommend further reading about land use and development impacts outside of this review.

Walkability

Whether or not a street or neighborhood is considered "walkable" depends on many things, including the amount of traffic, the type of infrastructure present, and the presence or absence of other amenities. **Litman (2008)** examined the "barrier effect" and its propensity to discourage walking, and found that such an effect continues to exist in cities where physical structures, such

as divided highways, or high traffic volumes on surface streets discourage or prevent people from walking into certain areas.[88] This effect is often created because of an institutional tendency to undercount walking trips, and therefore neglect to properly plan for them. It also has the tendency to discourage walking in general, therefore making walking less safe in many ways, as drivers become less accustomed to seeing – and looking out for – pedestrians on the roadway. This is the theory known as "safety in numbers", posited by **Jacobsen (2003)**, whose data analysis of walking in California found that the more pedestrians there are on the street, the safer they will be as drivers begin to expect them.[89] Barriers therefore perpetuate a negative cycle, and need to be mitigated if walking is to be encouraged.

Related research on walkability has mainly focused on two areas: design elements that affect walkability, and pedestrian level of service (LOS). The research reviewed in the design elements section includes studies that have attempted to objectively measure the impact of street design on the walking behavior of area residents or workers. The research in the pedestrian LOS section uses real-time pedestrian preference data to develop a model for redesigning streets to better meet pedestrians' needs. These two sections work together to present a clearer idea of strategies for designing walkable arterials and collectors in urban communities.

Street and Area Design Elements that Impact Walkability

In order to better understand successful walkable environments, **Southworth (2005)** conducted a literature review that included analyzing past and current pedestrian plans.[90] His review found that walkable neighborhoods are associated with populations who tend to walk more and weigh less, and who therefore may be at less risk for chronic disease linked to physical activity. In addition, walking has been associated with greater mental health. Walkable neighborhoods also encourage social equity in the transportation system, and have been associated with increased community vitality. Looking at national and international examples, Southworth concluded that walkable neighborhoods tend to have the following common characteristics:

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[88] **Litman, Todd**. 2008. Barrier Effect. Evaluating Nonmotorized Transport. Victoria, BC: Victoria Transport Policy Institute.

[89] **Jacobsen, P. L.** 2003. Safety in numbers: more walkers and bicyclists, safer walking and bicycling *Injury Prevention* 9:205-209.

[90] **Southworth, Michael**. 2005. Designing the Walkable City. *Journal of Urban Planning and Development* 131(4): 246-257.

- They are linked by a network of paths, which can include sidewalks along streets.
- The paths are connected to other modes of transportation such as bus or rail.
- The land uses are generally fine-grained and mixed, to provide multiple options for the local population.
- The paths are safe from both traffic and crime.
- They exhibit attention to details such as width, paving, landscaping, and lighting.
- The path context is visually stimulating and scaled to the pedestrian.
- The pathway is wide enough to fit 2-3 people walking side-by-side, continuous, and has a smooth enough surface that a wheelchair could travel over it easily.

Litman's (2004) research also suggested that walkable streets lead to greater community vitality, and that higher traffic volumes and speeds are correlated with lower levels of resident interaction. In addition, increased property values have been associated with walkable, New Urbanist neighborhoods. With regard to downtown business areas, pedestrianized commercial districts along main streets can contribute to urban revitalization, but they must be thoughtfully implemented to be effective. For example, many pedestrian streets failed in the 1950's and 60's due to the need for automobile access to businesses, which conflicted with the goal of creating a pedestrian realm. However, if a city works with its business owners to provide ample parking and/or public and non-motorized transportation access, a designated pedestrian area with destinations appropriate for travel by foot (i.e., restaurants and retail stores) could be quite successful, as exemplified by streets like Strøget, in Copenhagen, Denmark. This topic will be covered more thoroughly in Chapter IV.

In terms of public health benefits, health experts recommend at least 30 minutes of moderate exercise a day, at least 5 days a week, in intervals of 10 minutes or more. Walking is seen as one of the most practical ways to increase the amount of physical activity in a diverse population. Those who have few opportunities to participate in sports or formal exercise programs, such as the elderly, disabled, and lower-income, derive particular benefits from walking. More balanced transportation systems can contribute to enhanced public health by accommodating and encouraging active transportation. From a traffic safety perspective, international research suggests that shifts to non-motorized transport increase road safety overall.

Litman suggests measurement strategies that can help counter the trend among transportation planners of undervaluing walking. In addition, he suggests reexamining transportation agencies' funding priorities to mirror actual percentage of users, such as restructuring budgets from currently providing 1% of funding for the 10-15% of the general U.S. population who commonly walk, to providing a matching10-15% of the budget. This approach could be instrumental in encouraging the development of more walkable communities.

Zacharias (2001) reviewed several studies on pedestrian behavior, factors affecting route choice, and urban walking environments.[91] His findings suggested a link between the visual understanding of a network, termed "legibility", and pedestrian travel on that network. This need for understanding a network suggests that regular forms and spatial differentiation are important, while geometric variation should be limited. In addition, Zacharias' review examined research suggesting that although some complexity of space is desirable to maintain attention, spaces deemed too complex may be considered dangerous. These findings echo the work of Kevin Lynch, a seminal figure in the city planning movement whose study of pedestrians' relationships to the environment led to the concept that places should be "imageable"; i.e., a pedestrian should be able to hold an image of a place in her head.[92]

Research has also linked the choice to walk and physical comfort with regard to temperature, suggesting that warmer areas would benefit from tree planting in order to provide shade. Ambient sound has been shown to affect pedestrian behavior, as well: as traffic noise increases, pedestrians remember fewer details in the visual environment, walk more quickly, and look around less. This finding suggests that minimizing car traffic and speeds, or planting vegetation that could absorb some of the ambient noise, would enhance the pedestrian experience. Another study showed that pedestrians are likely to choose a pathway by evaluating the presence of others or public activity, suggesting that infrastructure that provides for pedestrians act as attractions even for passersby. Higher levels of connectivity have been associated with greater accessibility, suggesting that the decision to walk is encouraged by having multiple pathways to

[91] **Zacharias, John**. 2001. Pedestrian Behavior and Perception in Urban Walking Environments. *Journal of Planning Literature* 16 (1): 3-18
[92] **Lynch, Kevin**. 1960. *The Image of the City*. Cambridge, Massachusetts: MIT Press.

and from uses. Street lighting has been shown to be an important element in route choice of pedestrians, while other analysis has demonstrated that the presence of other people, signs, awnings, and furnishings are important factors in a person's choice to explore an unknown street.

Saelens and Handy (2008) conducted a meta-analysis of 13 reviews of the built environment correlates of walking, and reviewed 29 newer studies on the subject matter.[93] They found that five reviews concluded that accessibility based on distance to destinations is associated with increased walking. Six reviews found that aesthetic qualities, defined as the attractiveness of the environment, are associated with walking; however, this measure varied according to the study. Sidewalks and network connectivity were associated with walking in general. Neighborhood type, defined by level of "walkability" or age of development, was also a correlate of walking. Little correlation was found between walking for transportation and pedestrian infrastructure, although the researchers did not speculate as to why this might be the case. However, pedestrian infrastructure and aesthetics were associated with recreational walking. Walking to school appeared to be consistently positively associated with pedestrian infrastructure and traffic safety along the route, in addition to proximity. Sidewalk and traffic safety improvements were associated with increased walking in some studies.

Schlossberg et al. (2007) conducted a study on transit users' route choices to transit stops.[94] The researchers surveyed people who walked to five rail transit stops (one each in San Jose and El Cerrito, California, and three in Portland, Oregon) to find out what route they walked and their preferences in choosing a walking route. In addition, the researchers conducted an environmental audit of the streets and intersections around the transit stops. The analysis generated five key findings about pedestrian behaviors and preferences. First, the traditional one-quarter mile notion as the limit to how far people will walk is an underestimate by almost one-quarter mile. The average person in the study walked 0.47 mile to his/her transit stop, suggesting that land use planning for transit should consider a larger area than previously assumed.

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[93] **Saelens, Brian E.**, and Susan L. Handy. 2008. Built Environment Correlates of Walking: A Review. *Medicine & Science in Sports & Exercise* 40 (7S):S550-S566.
[94] **Schlossberg, Marc**, Asha Weinstein Agrawal, Katja Irvin and Vanessa Louise Bekkouche. 2007. How Far, By Which Route, and Why? A Spatial Analysis of Pedestrian Preference.

Second, pedestrians prioritize economy of time and distance over other reasons when choosing a route. This finding indicates that efforts to provide direct routes for pedestrians would likely be appreciated, and could potentially lead to an increased rate of walking. Third, safety was important to pedestrians, ranked next after economy of time. "Safety" included both traffic safety and safety from crime, although the qualitative answers seemed to indicate a greater concern about traffic safety. Fourth, the presence of sidewalks was a priority for 43% of the respondents (n = 328), and aesthetic factors such as landscaping were preferred by 35% of the respondents.

Finally, respondents in general enjoyed walking: 97% of the respondents "like(d) walking", while another 97% considered walking relaxing. In addition, 94% walked for exercise or health purposes – more than the number of people who walked because it was fast and/or cheap. This suggests the importance of creating an environment where more people are able to walk with greater enjoyment or convenience. Roadway-specific data from this survey indicated that the street sections that earned the lowest ratings as walkable environments almost all occurred on arterials and collectors. Ironically, these are the streets that generally contain the highest number of destinations, suggesting that redesigning arterial environments to meet pedestrians' needs for safety and enjoyment could potentially encourage many more people to walk for both utilitarian and recreational purposes.

Rajamani et al. (2002) used data from the 1995 Portland Metropolitan Area Activity Survey to examine the relationship between urban form measures and nonwork trip choice.[95] The Survey consisted of a two-day travel diary, individual and household socio-demographic information, and levels of service and travel times for driving, transit, walking and biking within and around the neighborhoods (census block groups). The researchers combined the survey data with GIS data from Portland Metro that provided information on land area per land use, population and housing unit densities, and local street network characteristics. The final sample included 2,500

[95] **Rajamani**, **Jayanthi**, Chandra R. Bhat, Susan Handy, Gerritt Knaap, and Yan Song. 2002. Assessing the impact of urban form measures in nonwork trip mode choice after controlling for demographic and level-of-service effects. Transportation Research Board.

individual home-based nonwork trips, of which approximately 28.2% were shopping and 30.5% were recreational in nature.

They then developed a model that considered the household and individual socio-demographic characteristics, trip characteristics, and urban form measures (land use mix diversity, accessibility, residential density, and local street network variables). The results indicated that the ratio of park area per housing unit positively influenced the propensity to walk for recreation, and that mixed uses encouraged walking as a mode for nonwork travel. The research does not specify what was considered "park area", but it seems likely that the classification was limited to traditional parks. However, even if the researchers considered only parks and not streets with park-like qualities, these findings suggest that including large amounts of greenery along urban arterials could possibly influence people's propensity to walk.

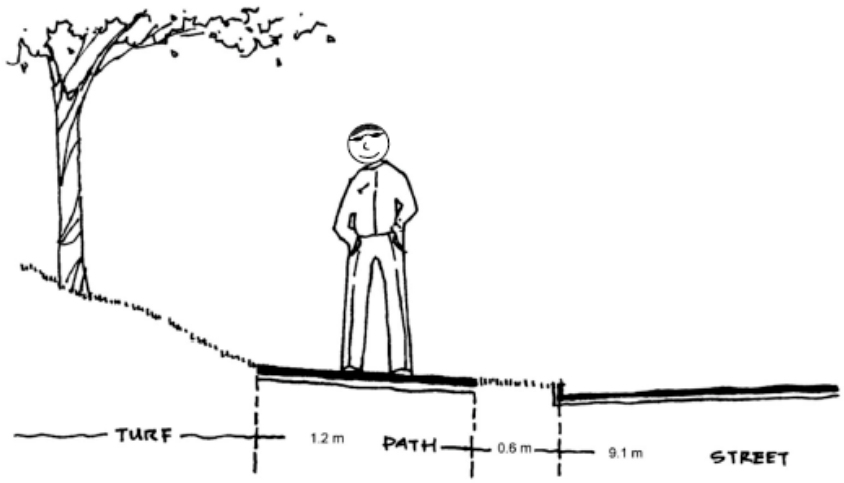
In addition, the results revealed that people were more sensitive to delay when walking or bicycling than when driving or taking public transit, perhaps due to weather concerns. This finding suggests that traffic devices such as leading pedestrian intervals, pedestrian crossing signals, and bicycle detection devices could encourage people to walk or bicycle by reducing delay. In addition, creating more direct paths, such as high quality sidewalks and bicycle lanes along the routes of major destinations, could encourage walking and bicycling.

Naderi (2003) looked at five pedestrian pathways in the same bioclimatic region of Texas that were built in the "clear zone" of the roadway, in order to understand what characteristics of the pathways influenced walkers' decisions to use them.[96] She found that walkers tended to associate the ambience or context of a place with whether or not it was a good place to walk. In addition, the edge of space, defined as either a sense of enclosure, environmental identity, or genius loci, was the single environmental variable that split the "good" from the "not good" sites for walking. Figure 2 shows a section of one of the pathways Naderi examined, which seemed to derive part of its identity from a tree canopy on one side. Naderi also found that survey respondents preferred a "natural" edge as opposed to an "urban" edge if they were walking

[96] **Naderi, Jody Rosenblatt.** 2003. Landscape Design in the Clear Zone. *Transportation Research Record* 1851: 119-129.

specifically for health purposes. She did not further define "natural" edge, but it is likely that lining the paths with trees - as opposed to having no barrier between the walker and traffic - would contribute to a more natural edge.

Figure 2. Rio Grande Drive, east side, College Station, Texas



(g)

Lee and Moudon (2006) examined the differences between walking for recreation and transportation purposes, in order to better understand how to promote both activities.[97] The researchers used socio-demographic data from the "Walkable and Bikable Communities Project" in Seattle, and GIS data, including distance to individual and grouped destinations, land use density, transportation conditions, and topography, to measure the environmental variables of the respondents' residential environments. The participants completed a survey with questions constructed to measure demographics, behavior, household characteristics, attitude, and neighborhood perception. Dependent variables were formed around frequencies of walking to work, school, groceries, other retail or service facilities, and for recreation or exercise. A 1-km buffer was used to define the neighborhood. A sample of 438 participants was selected for this analysis; no answer bias was found when the results of this sample were measured against partial data from respondents who did not complete the entire survey.

[97] **Lee, Chanam** and Anne Vernez Moudon. 2006. Correlates of Walking for Transportation or Recreation Purposes. *Journal of Physical Activity* 3(1): S77-S98.

The researchers developed a purpose model to differentiate between those walking only for transportation, only for recreation, both for transportation and recreation, or not at all. Transportation walking was considered to be any walking necessary to accomplish something, such as going to work or running an errand. In contrast, recreation walking was done just for the act of walking. The researchers also developed a frequency model based on the reported number of times that people walk during a usual week, differentiating between transportation and recreation.

The data indicated that the likelihood of walking for transportation was more affected by physical environmental variables than was recreational walking, and that the environmental variables associated with recreation differ significantly from those associated with transportation. These variables included average block size, number of street trees, total length of sidewalk, and distance to amenities such as the grocery, bank, and restaurants. The distance variables were much more important to those walking for transportation, as was the presence of street trees. Surprisingly, the presence of sidewalks was correlated only with recreational walking. Environmental factors also tended to be more strongly correlated with frequent walking than moderate walking, suggesting that a "supportive physical environment" may be key in promoting recommended levels of walking for health. In addition, people who walked for any purpose at all were more likely to reach the recommended level of physical activity than those who did not walk, suggesting that communities should provide facilities for both types of walking to promote public health.

The researchers recommended that strategies be tailored to individual communities given that socio-demographic data influenced the various models in different ways. The main limitation of the research was the homogeneity of the data – 90% of the respondents were white, and 54% had an annual household income of $50,000 or more. In communities where walking is more or less common due to socio-economic or demographic patterns, the application of the findings may need to be adjusted.

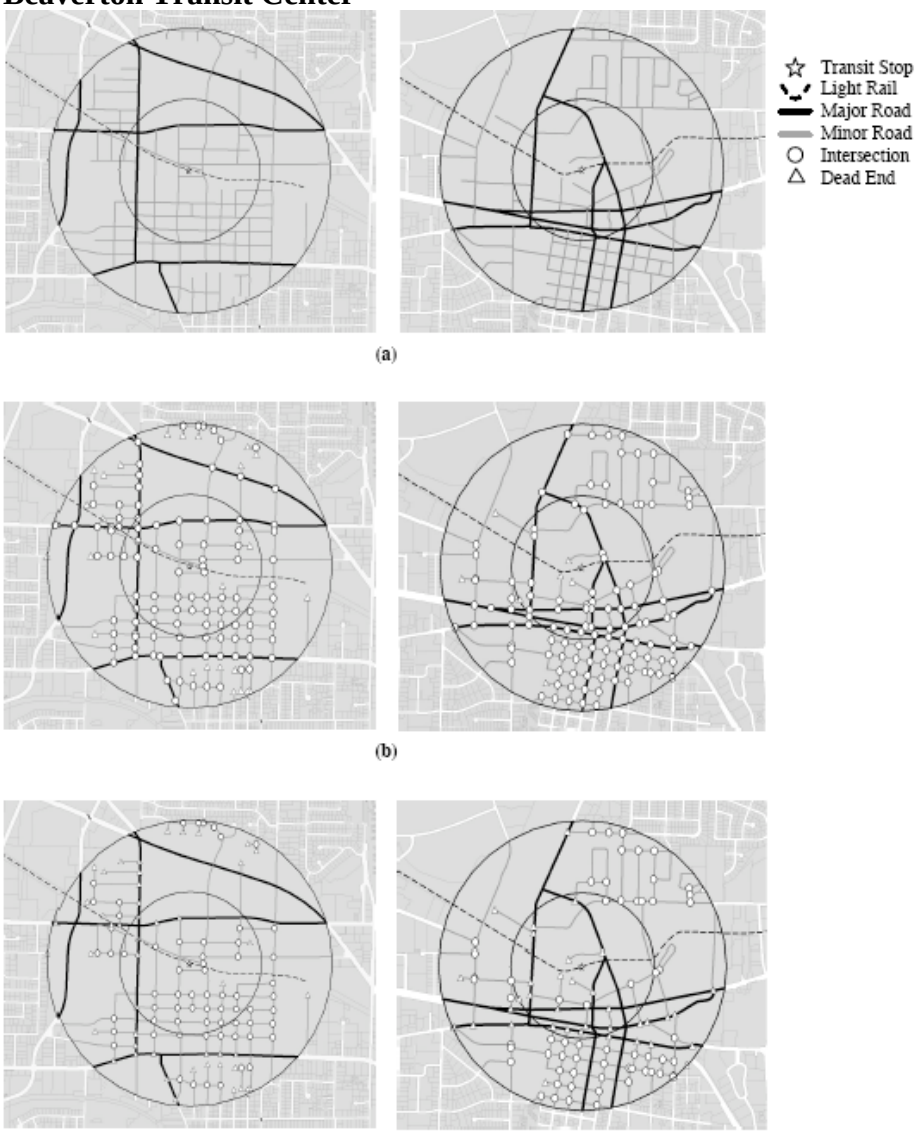
Schlossberg and Brown (2004) used GIS data for 11 different sites around the Portland Metro area to examine the walkability around selected transit-oriented developments.[98] The researchers analyzed the quantity of accessible paths, quantity of impedance paths (defined as heavily automobile-dominated streets), pedestrian catchment area, impedance pedestrian catchment area, intersection density, and density of dead ends for each site. The results were then mapped in order to visually compare the sites, as seen in Figure 3.

The data indicated that areas with fewer arterial streets were generally considered more walkable than areas with a greater ratio of arterial to minor roadways. Although the diagrams above show similar quantities of different street types as well as overall numbers of streets, the less walkable sites are characterized by the transit node being surrounded by high-volume arterials, isolating it from the rest of the local area. This finding suggests that arterials streets are acting as barriers due to a lack of pedestrian-friendly design features and the presence of multiple travel lanes.

Future research in this area would be more useful if pedestrian counts were combined with the analysis, as well as more information provided about the design characteristics and average speeds of the roadways. However, this piece provides a new way to measure walkability, which could be utilized as evaluation criteria or design criteria in corridor design near downtowns and areas that desire improved walkability. In addition, the GIS-based maps used here, when combined with additional measures, could be beneficial to Caltrans designers and engineers and partner communities in understanding the spatial characteristics of the communities through which Caltrans roadways pass. The maps could also help provide a greater context to designers and engineers when working within a community.

[98] **Schlossberg, Marc** and Nathaniel Brown**.** 2004. Comparing Transit-Oriented Development Sites by Walkability Indicators.

Figure 3. Visual comparison of TOD walkability for Gresham Central Station and Beaverton Transit Center



Gresham Central Station (left) and Beaverton Transit Center (right): (*a*) street network classification; (*b*) intersection visualization; (*c*) impedance-based intersection visualization

Pedestrian Level of Service

Although the phrase "level of service" (LOS) has traditionally been associated with automobiles, recent research has attempted to apply the concept to pedestrians to provide a scale by which they can gauge their comfort and ease of movement along a street. These efforts have been undertaken with the notion that pedestrians can give valuable guidance about preferences for or against roadway elements in order to guide future transportation design. Several pedestrian LOS models have now been developed, examining varying conditions along the roadway: signalized

intersections, arterials with sidewalks, mid-block crossings, etc. The results can be used to develop future performance measures regarding the accommodation of pedestrians on Caltrans corridors.

Petritsch et al. (2004) worked with the Florida DOT to examine pedestrian perceptions of the LOS of *signalized intersections*.[99] Through the "Walk for Science" in Sarasota, Florida, 50 participants, representing a good cross section of age, gender, and geographic origin, graded 23 intersection crossings along a 3-mile roadway section. The crossing distances ranged from 35–105 feet, along roadways with 2–6 lanes; some of the roadways had medians, while others did not. Fifteen-minute traffic counts in the curbside lanes showed from 0–267 vehicles, depending on location and time of day. The width of the outside motor vehicle lanes ranged from 10–12 feet, and most approaches had buffer widths of 0–10 feet between the roadway and the sidewalk. All roadway sections had sidewalks, which ranged from 4–7 feet in width. Posted speeds ranged from 25–45 mph, although observed 85th percentile speeds ranged from 28–44 mph.

The researchers developed a regression model that was able to explain 77% of pedestrians' perceptions of intersection LOS, with coefficients statistically significant at the 95% level. The model reflects that right-turn-on-red (RTOR) and permitted left turn conflicts significantly affect pedestrians' perceived LOS, as do the volume and speed of the perpendicular traffic. Pedestrians also seemed to be affected by the number of traffic lanes they had to cross, rather than the width of the street. This last finding is likely due to the fact that crossing three 10-foot travel lanes for a total 30 feet in width necessitates watching for three sets of cars, whereas two lanes of 15 feet each, albeit the same total width, only necessitates watching for two sets of cars. In addition, the data indicated that pedestrians were negatively influenced by delay, although the length of delay seemed to be less important than the fact that one was delayed at all.

The researchers also developed a model to measure right turn channelization islands, based on data collected from video simulations and adjusted to meet the aforementioned model. Right turn channelization islands seemed to negatively affect the pedestrians' perceived LOS, although

[99] **Petritsch, Theodore A.**, Bruce W. Landis, Peyton S. McLeod, Herman F. Huang, Srikalyan Challa, and Martin Guttenplan. 2004. Level of Service Model for Signalized Intersections for Pedestrians. Florida Department of Transportation.

the negative effect diminished as the volume of right-turning traffic increased. The researchers interpreted this change in preference as somewhat an acceptance on the part of the pedestrians: when there were fewer cars turning, the pedestrians perceived that they should have the right-of-way and that the right turn island was a nuisance; when there were many cars attempting to turn right, the pedestrians felt less safe and therefore regarded the island as a refuge. At approximately 100 right turns per 15-minute traffic volume, pedestrians seem to favor the islands. After incorporating this term, the final model was able to explain approximately 73% of the variation within perceived LOS, based on 1600 observations.

During the same "Walk for Science", **Petritsch et al. (2006)** looked at pedestrian LOS along *arterials with sidewalks* through a separate volunteer group.[100] Another group of 50 participants, representing similar demographic variation, walked along a 3-mile course on arterial roadways within and around downtown Sarasota, Florida. The participants were instructed to grade each section, the beginnings and ends of which were marked by course signs, on a scale of A-F; participants could change their grades at any time. The data indicated no significant difference between how the participants scored the sections according to demographic characteristics.

The results revealed that for an arterial roadway with sidewalks, the pedestrian LOS when walking along the street decreases in correlation with the total width of driveway and intersection crossings, as well as with the amount of traffic on the adjacent roadway. The researchers developed a model that was able to explain 70% of the variation within the LOS scores given by the participants. They interpreted the model to be more useful as a planning tool rather than as an operational evaluation method. They also recognize that the model is limited to roadways with sidewalks, and did not examine roadways with more than four through lanes of traffic, so it may not accurately evaluate roadways with more than four lanes. In addition, none of the participants were mobility or visually impaired, so the model may not accurately reflect the LOS for pedestrians with such impairments.

[100] **Petritsch, Theodore A.**, Bruce W. Landis, Peyton S. McLeod, Herman F. Huang, Srikalyan Challa, Cherie L. Skaggs, Martin Guttenplan and Venkat Vattikutti. 2006. Pedestrian Level of Service Model for Urban Arterial Facilities with Sidewalks. Florida Department of Transportation.

In order to better understand pedestrian LOS at *mid-block crossings*, **Baltes and Chu (2002)** hired 96 participants to grade 20 mid-block crossings in Tampa, Florida, and 13 mid-block crossings in St. Petersburg, Florida.[101] The participants, 68% of whom were women, graded 767 mid-block crossings total; for each crossing, they were given 3 minutes to cross and then asked to note conditions that impeded their ability to cross safely. The streets ranged from 28–108 feet in width, averaging 55.27 feet. Average speeds ranged from 23–45 mph, with a mean of 32.12 mph. The researchers analyzed the participants' scores and found that the perceived level of crossing difficulty increased with higher total volumes of traffic, higher numbers of turning movements, higher average speed, and greater crossing width of streets. Unfortunately, the researchers did not give measurements other than the minimum, maximum, median, and mean values, making it difficult to draw detailed conclusions.

The data revealed that the perceived LOS increased as the width of painted or raised medians increased. The presence of a crosswalk also increased the perceived LOS. The presence of pedestrian signals and the cycle length were found to be statistically significant, although more analysis needs to be done to better understand their effects on pedestrian LOS. The final model was able to explain 34% of the variation in LOS scores given by the participants, which the researchers considered reasonable, but which leaves much of the results unexplained.

Summary of Key Research Findings

The following is a summary of the key findings on the research related to corridor roadside design and walkability:

- Environments with good aesthetic qualities that are perceived to be attractive are associated with walking.
- The presence of sidewalks and network connectivity were associated with walking.
- The presence of pedestrian infrastructure and aesthetics were particularly associated with recreational walking.
- Walking to school appears to be consistently positively associated with the presence of pedestrian infrastructure and traffic safety along the route.

[101] **Baltes, Michael R.** and Xuehao Chu. 2002. Pedestrian Level of Service for Mid-block Street Crossings. *Transportation Research Record* 1818: 125-133.

- A number of studies have associated sidewalk and traffic safety improvements with increased levels of walking.
- Roadway-specific data from a survey of transit users' route choices to transit stops indicated that the street sections that earned the lowest walkability ratings almost all occurred on arterials and collectors.
- People seem to be more sensitive to delay when walking or bicycling than when driving or taking public transit.
- Areas with fewer arterial streets seem to generally be considered more walkable than areas with a greater ratio of arterial to minor roadways.
- Pedestrians' perceptions of level of service seem to be more affected by the number of traffic lanes they must cross, rather than by the width of the street.
- Right turn channelization islands seem to negatively affect pedestrians' perceived level of service.
- Pedestrian level of service when walking along a street was found to decrease in correlation with the total width of driveway and intersection crossings, as well as with the amount of traffic on the adjacent roadway.
- Pedestrians' perceived level of crossing difficulty was found to increase with higher total volumes of traffic, higher numbers of turning movements, higher average speed, and greater crossing width of streets.
- Pedestrians' perceived level of service increased as the width of painted or raised central medians (separating directional traffic flows) increased.
- The presence of crosswalks seems to increase pedestrians' perceived level of service.

Future Research Needs

One serious challenge for transportation planners and engineers concerned about pedestrian provision is how to encourage walking when land uses are far apart. More research is needed on factors other than distance that affect a person's decision to walk. For example, how much do street trees and landscaping affect a person's comfort when walking, and influence the decision to – or not to – walk?

- Research using a matched pair of streets, or matched sections of a street, on which to conduct studies not confounded by differences in the variables. For example, an ideal

street for understanding the effects of the presence of large street trees would have such trees on one section and not on another section, but the land uses, traffic volume, and socio-demographic variables would all be roughly approximate. 3-D computer modeling of various treed roadways may provide insights into future design. This type of research has just begun to be used, and offers great potential for future studies. It may also help quantify the benefits and costs of street trees in terms of aesthetics and emotional/spiritual value.

- Research directed at understanding the full value to pedestrians of amenities such as street trees and benches or lighting would be helpful.
- The deleterious effects of transportation facility barriers on walkability need to be more fully understood, particularly the barriers caused by arterial streets. For example, research needs to be directed at determining if arterial streets with certain types of roadside designs discourage or encourage pedestrian activity. For transportation facility designers, the use of existing pedestrian numbers to justify improvements should come with the caveat that current numbers are low due to a variety of barrier effects, and that those effects will need to be mitigated before increases in the number of pedestrians and amount of pedestrian activity can realistically be expected.
- Research directed to gaining access to data on pedestrian activity (not always a priority for transportation agencies) is important. Schwartz et al. worked with the Bureau of Transportation Statistics to review existing data and data needs as indicated by surveys of planners, advocates, and researchers at universities, organizations, and all levels of government agencies.[102] Primary and secondary data sources were categorized, and priorities for data needs were identified as described in Table 15. One of the highest identified priorities is to better understand the number of user trips taken per mode. Installment of devices such as pedestrian counters at major arterial intersection could mitigate this problem.

[102] **Schwartz, William,** Christopher Porter, David Mednick, Wendell Fletcher, William Mallett and Joanne Sedor. 2000. Bicycle and Pedestrian Data: Sources, Needs, & Gaps. U.S. DOT – Bureau of Transportation Statistics.

Table 15. Assessment of Data Priorities

Type of data and description	Quality of existing data	Priority for better data
Usage, trip, and user characteristics		
Number of bicyclists and pedestrians by facility or geographic area	Poor	High
User and trip characteristics by geographic area or facility	Fair	Medium/high
User preferences		
Relative preferences for facility design characteristics and other supporting factors	Fair	Medium
Facilities data		
Characteristics relating to quality for bicycle or pedestrian travel	Fair	Medium
Crash and safety data		
Specific bicycle- and pedestrian-relevant crash variables	Fair	Medium/high
Data regarding crashes that do not involve a motor vehicle	Poor	Medium
Secondary data		
Safety and demand impacts of design features	Fair	High
Safety and demand impacts of policies, programs	Fair	Medium

Bikability

As mentioned in Chapter I, there has been a clear shift in transportation policy to promote travel by bicycle in the U.S., driven in part by physical health and environmental concerns. Cycling provides a way to by physically active while also reducing the amount of air pollution admitted per capita. This reduction in air pollution improves both individual and planetary health, and, in conjunction with record high gas prices in 2008, makes cycling a seemingly benign mode of transport that could serve many more than the current 1% of U.S. trips. The difficulty of providing for this latent demand is in knowing what incentives or street design qualities would

encourage potential riders to choose bicycling for various trips. In addition, some researchers have wondered if focusing on providing for potential cyclists would result in ignoring current cyclists' preferences. There is also the divide between those who cycle for utilitarian purposes, such as to work or to the store, and those who cycle for recreation. Because these groups often travel different routes, they may also have different preferences with regard to facility type.

As is the case for walkability, it is important for transportation planners and engineers to understand the impact of the "barrier effect" on bicyclists. Whether or not a street or neighborhood is considered "bikable" depends on many things, including the amount of traffic, the type of infrastructure present, and the presence or absence of other amenities. Jacobsen's "safety in numbers" theory is also applicable, as bicyclists become safer just by having more of them on the road and therefore causing drivers to be more cautious and aware of their presence. This section presents several studies that have attempted to better understand these complexities. It is divided into three sub-sections: factors affecting bicycling demand, cyclists' preferences for travel facilities, and bicycle level of service.

Factors that Influence Bicycling Demand

Several studies have found that the presence and type of bicycle facilities influence bicycle ownership and ridership at different levels. Some studies found that many bicyclists will ride regardless of the facilities, but have a clear preference for facility type; other studies found that the presence of certain bicycle facilities could encourage non-cyclists to ride bicycles. **Dill and Carr (2003)** sought to understand the impact of bicycling facilities on commute patterns in metro areas in the United States.[103] Forty-three cities with populations of over 250,000 provided data on their Class I (separated bicycle paths) and Class II bicycle facilities (striped on-road bicycle lanes). The researchers combined this data with the Census 2000 Supplemental Survey (C2SS) as well as the long form 2000 Census data to compare the demographics, commute patterns, land use, and socio-economic characteristics of the various cities.

[103] **Dill, Jennifer** and Theresa Carr. 2003. Bicycle Commuting and Facilities in Major U.S. Cities. *Transportation Research Record* 1828: 116-123.

The researchers were able to build a model that explained 34% of the variation among cities and the various factors affecting bicycle usage. Although this left two-thirds of the variation unexplained, they believed that the findings were a good start to better understanding bicycle commuting. The model indicated that the number of Class II bike lanes per sq. mi. explained the largest share of bicycle commuting rates, and that vehicle ownership and the number of days of rain negatively affected commuting patterns. However, the findings also suggested that rain is not as serious of an impediment as some might think: 3 of the top 10 cycling cities have more than 100 days of rain per year. The results also indicated that the percentage of bicycle commuting is significantly correlated with the gasoline price variables, a finding that is particularly important given the record gasoline prices in 2008. This finding may represent a significant opportunity to encourage bicycling in cities via the provision of bicycling facilities.

The model also indicated that for typical U.S. cities with populations greater than 250,000, each additional mile of Class II bike lanes per sq. mi is associated with roughly one percentage point increase in the percentage of bicycle commuters. The authors suggest that future research dealing with other types of cycling could be even more revealing of the impact of bicycling facilities, as commute travel now only comprises 20% of total U.S. travel.

In another study, **Dill and Voros (2007)** interviewed a random sample of adults in Porltand, Oregon, to understand the factors that influence whether or not they bicycle.[104] The researchers also used GIS to map out the street network and presence or absence of bicycle lanes within ¼ mile of the respondents' homes. The data analysis showed that a significant drop-off in regular and utilitarian cycling occurred at age 55 years and above. In addition, vehicle availability was associated with rates of utilitarian cycling: 28% of respondents in households with less than one vehicle per adult cycled for utilitarian purposes, as compared to 20% of those in households with more than one vehicle. Although there was no difference in current cycling patterns between those who did and those who did not cycle to school as children, current cycling patterns were significantly positively associated with how often people rode their bikes for fun or to places other than school as a child.

[104] **Dill, Jennifer**, and Kim Voros. 2007. Factors Affecting Bicycling Demand - Initial Survey Findings from the Portland, Oregon, Region. *Transportation Research Record* 2031:9-17.

Peer norms seemed to influence cycling rates: 32% of respondents with coworkers who cycle regularly also cycled regularly, as compared to 16% of those who cycle regularly but whose coworkers do not. There was also a positive association between regular cycling and observing other adults cycling on one's street at least once per week. Regarding untapped demand for cycling, the data showed that younger adults were significantly more likely to want to increase current cycling frequency, as were men in general, and respondents who cycled for fun rather than to school as a child, whose coworkers or housemates currently cycled regularly, and who observed others on their streets cycling.

Utilitarian cycling in particular was positively associated with living in neighborhoods with higher street connectivity and being closer to downtown (variables which were found to be correlated in the analysis). Regular and utilitarian cycling was also positively associated with quiet, well-connected streets leading to desirable destinations (similar to Portland's bicycle boulevards), positive attitudes toward biking, a dislike for driving, and environmental values (concerns about air quality and therefore a desire to drive less; desire not to see more highways built). However, slow neighborhood traffic was not associated with frequency or type of cycling. These findings suggest that arterial streets, due to their general directness of route, might be ideal for the provision of bicycle facilities that would allow for a more direct and connected network. This provision could in turn encourage higher amounts of utilitarian cycling.

Bicycle lanes were found to be both positively associated and not associated with increased frequency of regular and utilitarian cycling. Dill and Voros attribute this mixed finding to cyclists' knowledge of bicycle lanes near their homes as compared to people who do not bicycle. They also acknowledge that the ¼-mile designated "neighborhood" may not have accurately described the area that respondents deemed their true neighborhoods, leading to mixed interpretations of the question. Barriers to cycling were cited as too much traffic (56% of those who wanted to cycle more cited this); lack of bike lanes or trails (37% - associated with respondents who had significantly fewer bike lanes within a mile of their homes); lack of safe places to bike nearby (33%); too many hills (30%); and distances to destinations too great (23%).

Rietveld and Daniel (2004) examined the effects of municipal policies on bicycle usage in 103 Dutch municipalities, in order to better understand the variation in cycling rates between and within cities.[105] Using data the U.S. Census and the Dutch Cyclists' Union, the researchers performed a regression analysis on bicycle usage in the cities examined. The data included city and environmental characteristics and local policy efforts, in addition to data on cyclists' satisfaction with regard to policies. The policy/planning measures of interest included: the number of stops or turns imposed on cyclists (per unit distance); auto parking cost; hindrances such as the proportion of time spent walking or biking slowly, the obligation to give priority at a crossroads, and the quality of the road surface; the speed of the trip in comparison with the automobile; and the level of safety for the cyclist. In order to examine the data more closely, the researchers compared the 15 cities with the highest bicycling mode share to the 15 cities with the lowest bicycling mode share.

The researchers prepared a model that included 26 of the variables, which was able to explain roughly 71% of the variation in cycling rates within and between cities. The results suggested a strong positive correlation between government policy and increased bicycle use. The results could be divided into significant policy variables and significant city form and environmental variables, all of which are applicable to arterial streets. The significant policy variables suggested the following:

- Making a bicycling trip 10% faster than the same trip via auto increases bike usage by 3.4%.
- Reducing stops by 30% per km leads to a 4.9% increase in bicycle usage.
- Raising parking costs by ~ 22 cents/hr increases bike usage by 5.2%.
- Reducing hindrances by 25% leads to a 1.3% increase in bicycling.
- Improving bicycle safety by 1 fewer serious accident per 1,000,000 bicycle-km traveled in four years leads to a 1.1% increase in cycling.
- Lowering the risk of theft of or damage to bicycles (e.g., by providing secure parking) encourages cycling.

[105] **Rietveld, Piet** and Vanessa Daniel. 2004. Determinants of bicycle use: do municipal policies matter? Department of Spatial Economics, Vrije Universiteit, De Boelelaan 1105, 1081 Amsterdam, HV, Netherlands.

These results imply that there are essentially two ways of encouraging bicycle use: (1) improving the attractiveness of a mode by reducing its generalized costs, and (2) making competing modes more expensive. This combination of push and pull policies is a rather general result found in transportation research, and it also appears to apply to bicycle use. Although the study looks exclusively at cities in The Netherlands, inference can be made to U.S. cities. One important consideration is the difference in general policy, evidenced by the fact that the cities with "low" bicycling rates in the study still have over 20% of the travel by bicycle; this suggests a different approach to traffic planning – one which could become increasingly important as Caltrans seeks to minimize environmental, public health, and harmful economic impacts on its partner communities.

Xing et al. (2007) studied the factors associated with bicycle ownership and use in six small U.S. cities.[106] Analysis of the data revealed that individual and social environment factors influenced the propensity to bicycle more than physical environment factors did. However, this finding must be considered in light of the reality that individual and social factors are not separate from physical environmental elements. For example, a person's perception of safety while bicycling was associated with frequency of cycling, and the presence of bicycling infrastructure influences perceptions of safety. In addition, a separate model revealed that for each additional mile of bicycle lane in a city, people were 5% more likely to own a bicycle and to have ridden it during the 7 days prior to the survey.

Moudon et al. (2005) examined the relationship between cycling frequency and features of the built environment.[107] After analyzing the data from a sample of 608 randomly selected King County, Washington, residents, the researchers found evidence that proximity to a bicycle trail and the perception of nearby trails or bicycle lanes are positively associated with cycling. In addition, the survey data revealed a strong stated preference for an increase in the number of bicycle lanes and trails, better lighting along the roadway, and bicycle parking at destinations to encourage cycling. However, an objective analysis of roadway characteristics in the study area

[106] **Xing, Yan**, Susan L. Handy, and Theodore J. Beuehler. 2008. Factors Associated with Bicycle Ownership and Use: A Study of 6 Small U.S. Cities. In *Transportation Research Board*. Washington, D.C.
[107] **Moudon, Anne Vernez**, Chanam Lee, Allen D. Cheadle, Cheza W. Collier, Donna Johnson, Thomas L. Schmid, and Robert D. Weather. 2005. Cycling and the Built Environment. *Transportation Research Part D* 10:245-261.

suggested that bicycle lanes, traffic volume and speed, and topography did not significantly influence bicycling rates.

The researchers suggest that these mixed findings are due to the unexpectedly high level of cyclists in the sample population, and the significant influence of socio-demographic and social variables on whether or not one bicycles. The authors also suggest that these results be interpreted as motivation for building a more comprehensive bicycle network within cities, and worrying second about the exact nature of the facilities provided (i.e., bicycle boulevard versus bicycle lane versus bicycle trail). They also caution that more research should be done to better understand the broader relationship between bicycle facilities and various rider demographics.

Parkin et al. (2007) assessed perceived cycling risk and route acceptability for potential cyclists in order to better understand variables that affect bicycling demand.[108] They found that cycling along residential roads was associated with increased risk, particularly if there was on-street motor vehicle parking. However, parked vehicles along a busy road did not appear to increase perceptions of risk. High amounts of automobile traffic were also positively associated with increased perceptions of cycling risk; bicycle lanes may help mitigate this perceived risk, but cannot do so completely. The researchers also found that the presence of a bus lane led to decreased perceived cycling risk, which the authors attributed to greater separation from automobile traffic. Bicycle facilities on straight routes with signalized junctions were positively associated with decreased perceptions of cycling risk, but not in the case of right turns, which increased perceptions of risk regardless of the circumstance. Roundabouts were also associated with increased perceptions of risk. Overall, the models were only able to explain about 27.5% of the variation in one's decision to bicycle or not, corroborating what previous studies have found about the complex interaction of factors related to one's decision about bicycle travel.

[108] **Parkin, John**, Mark Wardman, and Matthew Page. 2007. Models of Perceived cycling risk and route acceptability. *Accident Analysis and Prevention* 39:364-371.

Gonzales et al. (2004) conducted a survey of the off-street bicycle paths installed in the last decade by the Rhode Island Department of Transportation.[109] Approximately 1300 bicyclists and walkers were interviewed at each site, with at least 270 respondents at each of the four sites. Of that total, 688 responded to a longer, at-home survey, which was mailed or emailed back to the researchers. The survey respondents indicated that although the off-road pathways were prized, a lack of on-road connecting facilities precluded many riders from commuting via bicycle, presumably because they could not reach the paths in what they deemed a safe manner. Responses also evidenced a clear association between choosing to commute by bicycle and an intention to improve one's health, suggesting an untapped demand for healthy commuting choices due to a lack of bicycle commuting facilities (i.e., bicycle lanes, bicycle boulevards, etc.) that lead to employment or other utilitarian destinations. The survey also found that respondents spent an average of $1-5 per outing, indicating a small but consistent economic benefit of providing bicycling facilities. Overall, the respondents overwhelmingly supported the use of tax dollars to construct the bicycling facilities, for which there seems to be high demand.

Bicyclists' Preferences for Travel Facilities

Several studies have been conducted to understand cyclists' preferences for facilities. These studies have looked both at revealed preferences, which use observations and real data of cyclists' behavior to draw conclusions, and stated preferences, which come from interviews or surveys of cyclists to learn what they would prefer if given the choice between facilities. These studies should aid transportation planners and engineers in designing facilities that will appeal to greater numbers of people and hopefully encourage more bicycling riding as a mode of transportation.

Wardman et al. (2007) examined both revealed and stated preferences of cyclists in the United Kingdom.[110] The survey data revealed that a majority of cyclists rode to work on roads without cycling facilities, but that providing improved cycling facilities would encourage a higher mode share of cycling. The researchers built a model in which the best-case scenario was assumed to

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[109] **Gonzales, Liliana**, R. Choudary Hanumara, Carol Overdeep and Steven Church. 2004. 2002 Bicycle Transportation Survey; Developing Intermodal Connections for the 21st Century. University of Rhode Island Transportation Center.

[110] **Wardman, Mark**, Miles Tight, and Matthew Page. 2007. Factors Influencing the Propensity to Cycle to Work. *Transportation Research Part A* 41:339-350.

be separated cycleways; this assumption was associated with a predicted 55% increase in the number of cyclists, although the number of automobiles on the road was only projected to decrease by 3%. The data also indicated that shower and indoor parking facilities were prized by cyclists, as were outdoor parking facilities. The researchers concluded that upgraded facilities would benefit cyclists, but that to seriously increase cycling mode share, financial incentives from businesses would also be necessary.

Tilahun et al. (2007) developed a model to evaluate stated preferences regarding various bicycling facilities.[111] The respondents included regular cyclists, occasional cyclists, and non-cyclists. Using travel time to work as the currency, the researchers gauged respondents' preferences between the following facilities, ranked in quality by the researchers (A being the highest quality and E being the lowest): A) an off-roadway cycling facility, B) a street with a bicycle lane but no on-street parking, C) a street with a bicycle lane and on-street parking, D) a street with neither a bicycle lane nor on-street parking, and E) a street with no bicycle lane but on-street parking. The model found that, on average, respondents were willing to travel farthest on an alternate facility if the other option was a street that had no bike lane but did have on-street parking (option E). Ironically, option E represents the most pervasive street type in American cities, yet bicyclists are expected to be comfortable riding on it. Although the second least-popular facility was the street without a bike lane or parking (D), followed by the street with a bike lane and parking (C), participants were less willing to sacrifice travel time for those facilities.

On average, subjects were willing to travel approximately 23 more minutes to an off-roadway bicycle facility if it were available, instead of bicycling in mixed traffic next to on-street parking. The logit model showed significant heterogeneity among subjects, supporting the use of a mixed model, but also indicated a general aversion to longer trips (as expected). The model also showed that all facility improvements positively and significantly influenced participants' choices to varying degrees. In general, the presence of a bicycle lane had a much greater impact on the odds of choosing the higher quality facility than did the elimination of on-street parking

[111] **Tilahun, Nebiyou Y.**, David M. Levinson, and Kevin J. Krizek. 2007. Trails, lanes, or traffic: Valuing bicycle facilities with an adaptive stated preference survey. *Transportation Research Part A* 41:287-301.

or the presence of an off-roadway facility. Seasonality was negatively associated with the propensity to choose the higher-quality facilities, possibly because the off-road path may not be plowed or de-iced in the winter as compared to the roadways. Although the model deemed it insignificant, women were more likely to choose the higher quality (and perceived as safer) facilities than the men in the study.

The model also indicated that the "cyclist" variable (whether or not the respondent used the bicycle as the main mode of transport during at least the summer months) was highly insignificant, suggesting that experience did not bias answers in either direction. In addition, individuals from larger households tended to choose the travel facility with the shorter travel time, likely reflecting greater time constraints. Based on the model, which had a base travel time of 20 minutes, a bike lane was found to be valued at 16.41 minutes (the amount of extra time a person would ride if a bike lane were present), avoiding on-street parking was valued at 9.27 minutes, and an off-roadway improvement was valued at 5.13 minutes of travel time.

The results of the model gave no evidence to suggest that those who cycled regularly and those who did not preferred different facilities. The authors found this to be an encouraging discovery, eliminating the need to focus on one group over the other. Although this type of modeling presents a potentially useful way to gauge cyclists' and others' preferences for facilities, it was limited by not including data on the effects of speed limits or ADT on the roads, which also influence whether or not a person chooses a certain facility. Still, for planning purposes, this model presents clear preferences for situations other variables are held equal.

Hunt (2007) examined influences on bicycle use through a stated preference survey distributed to current cyclists.[112] Data analysis revealed that cyclists are more attracted to shorter length trips, suggesting that an increase in direct connectivity would result in increased numbers of cyclists. In addition, there was a clear preference for exclusive bicycle facilities, although it is not clear that such an increase would induce demand. The modeled data indicated that cyclists preferred bicycle lanes to the extent that they would trade 4.1 minutes in a bicycle lane for each single minute they would have to spend in mixed traffic; for bicycle paths, the ratio was 2.8:1.

[112] **Hunt, J.D.** 2007. Influences on Bicycle Use. *Transportation* 34:453-570.

This finding indicates that these cyclists preferred bicycle lanes to bicycle paths (assuming the paths were mixed-use, with pedestrian traffic). Secure bicycle parking was also a significant factor in whether or not someone chose to bicycle.

Garrard et al. (2008) examined the role of bicycle infrastructure in promoting cycling specifically for women.[113] The researchers analyzed data gathered from observations of cyclists' choices of routes around downtown Melbourne, Australia. Although the original analysis suggested that females preferred on-road bike lanes and roads without bicycle facilities to off-road paths, this finding was reversed after adjusting for distance from the GPO; female cyclists showed a preference for off-road paths over the roads without bicycle facilities (OR=1.43), and on-road bicycle lanes (OR=1.34). The data also indicated that males cycled approximately 0.5 km greater average distance from the GPO than the females, and that, after adjusting for distance, the proportions of females and males were similar between on-road bicycle facilities and roads without bicycle facilities. This finding suggests that the provision of bicycle lanes may not be enough to encourage women who do not currently cycle to begin cycling. This research did not account for effects of roadway conditions or ADT, which likely influence the path a person chooses to take. In addition, the conclusions of the research would have been strengthened by a user survey, which could have more directly determined why the female cyclists chose to cycle where they did.

Alta Planning + Design (2004) examined cyclists' behavior after the installation of sharrows on local streets.[114] A sharrow is a large white symbol painted on the roadway to indicate that both bicycles and cars should share the lane (i.e., there is no separate bicycle lane); see Figure 4 for a photo of the symbol. The sharrow is used when there is not enough space on routes preferred or frequently traveled by bicyclists to stripe a separate bicycle lane.

[113] **Garrard, Jan**, Geoffrey Rose, and Sing Kai Lo. 2008. Promoting transportation for cycling for women: The role of bicycle infrastructure *Preventive Medicine* 46: 55-59.
[114] **Alta Planning + Design**. 2004. San Francisco's Shared Lane Pavement Marking: Improving Bicycle Safety. San Francisco: San Francisco Department of Parking & Traffic.

Figure 4. Representative example of a sharrow symbol
(This particular example comes from Paris)

Observations showed that when the marking was present, cyclists tended to increase their lateral spacing from parked cars by approximately 8 inches, thus encouraging them to ride outside of the "door zone" (the zone in which a cyclist could be hit by someone opening a car door). The markings also encouraged cyclists to ride away from parked cars when being passed by a moving vehicle, although the distance was less: 3–4 inches. Observations also indicated that the distance between cyclists and passing vehicles increased by over 2 feet. Even when no cyclists were present, the sharrow marking influenced passing traffic such that it was approximately 1 foot farther from parked cars than normal.

The markings were also positively associated with reductions in "deviant" cyclist behavior. Observations revealed a significant reduction in the number of sidewalk bicycle riders, as well as the number of wrong-way riders (down by 80% where sharrows or chevrons were present).

These results suggest a clear preference toward bicycling in an area designated for cyclists – in this case, over sharrows that are meant to inform drivers of a need to share the road.

Bicycle Level of Service

Like the efforts for pedestrian LOS, recent research has attempted to define bicycle LOS by quantifying the "bike-friendliness" of a roadway.[115] These efforts have been undertaken with the notion that bicyclists can give helpful feedback about preferences for or against roadway elements in order to guide future transportation design. Several bicycle LOS models have now been developed, examining varying conditions along the roadway, such as arterials and individual roadway segments. The results can be used to develop future performance measures regarding the accommodation of bicycles on Caltrans corridors.

To evaluate bicycle LOS for *arterials*, **Petritsch et al. (2006)** recruited 63 volunteers to ride a course of arterial and collector roadways in Tampa, Florida.[116] A main objective of this experiment was to evaluate the ability of the established bicycle LOS model for *individual roadway segments* to accurately predict LOS for arterials. The course was approximately 20 miles long, broken into 12 roadway sections. The sections ranged from 0.3–1.5 miles in length, and were marked at the beginning and end by course signs. The roadways had a range of characteristics: 2–6 lanes, divided and undivided, with and without bike lanes and shoulders, and varying speeds, driveway densities, and pavement conditions. Traffic volumes ranged from 5–320 motor vehicles during a 15-minute period, and posted speeds ranged from 30–50 mph. The width of outside motor vehicle lanes ranged from 10.5–15 feet, and striped bike lanes and paved shoulders ranged from 0–9 feet. The cyclists represented a range of skills and ages, and the gender was split 41% female and 59% male. Similar to the pedestrian LOS experiments highlighted in this review, the cyclists were instructed to grade each roadway section on a scale of A–F. To control for bias from fatigue, half of the participants rode the second part of the course first.

The data indicated that the section of the course with the lowest overall scores had no bicycle

[115] League of Illinois Bicyclists. Bicycle Level of Service. http://www.bikelib.org/roads/blos/. (Oct. 7, 2008).
[116] **Petritsch, Theodore A.**, Bruce W. Landis, Herman F. Huang, Peyton S. McLeod, Daniel Lamb, Waddah Farah and Martin Guttenplan. 2006. Bicycle Level of Service for Arterials. Florida Department of Transportation.

lanes or paved shoulders, and had some of the higher traffic volumes during the event. This finding seems to underscore the importance of providing a separate space for bicyclists to feel comfortable, particularly when riding alongside higher volumes of traffic. In addition, females on average graded sections lower than males did; likewise, participants over age 40 on average graded sections lower than their younger counterparts, both at a 95% significance level. These findings indicate that planning for non-motorized transportation will likely be more successful if the more timid cyclists are seriously considered. Interestingly, there were no significant grading differences based on riding frequency of the participants, suggesting that cyclists do not necessarily become accustomed to certain types of facilities, such as roadways with high traffic volumes but without bike lanes.

Open-ended questions revealed that the presence or absence of bike lanes was the most commonly cited reason for grading a roadway section "A" or "B", or "E" or "F", respectively (approximately 22%). Traffic volumes were the second most cited reason (~16%), followed by roadway/pavement condition (~11%) and accommodation/space (~5%). The researchers modified the previously developed bicycle level of service model for *individual roadway segments* (of any street type) to include the number of unsignalized intersections, resulting in a model specific to *arterials*, which was able to explain 72% of the variation in LOS scores. They caution that since the research was conducted in an urban area, the results may not be transferable to a rural area. In addition, the model also may not accurately reflect conditions where the number of side streets is low due to managed access.

There are a couple of serious limitations of this model. First, it does not control for land use along the arterial, and assumes that driveway crossings are not important. However, the level of driveway crossings along an arterial may be substantially different along strip commercial areas than downtown or main street areas. Second, this model was based on the subjective grading of survey participants, all of whom were comfortable enough bicycling to participate. Therefore, this model should not necessarily be used to create conditions to inspire non-cyclists to bicycle, but rather to make cycling easier and more convenient for current cyclists.

Summary of Key Research Findings

The following is a summary of the key findings on the research related to corridor roadside design and bikability:

- In typical U.S. cities with populations greater than 250,000, each additional mile of Class II bike lanes per sq. mi is associated with roughly one percentage point increase in the percentage of bicycle commuters.
- People perceive the following as barriers to cycling: too much traffic, lack of bike lanes or trails, lack of safe places to bike near to where they live, and long distances to destinations.
- Several factors that may lead to increased bicycle usage:
    - Making a bicycling trip 10% faster than the same trip via auto increases bike usage by 3.4%.
    - Reducing stops by 30% per km leads to a 4.9% increase in bicycle usage.
    - Raising parking costs by ~ 22 cents/hr increases bike usage by 5.2%.
    - Reducing hindrances by 25% leads to a 1.3% increase in bicycling.
    - Improving bicycle safety by 1 fewer serious accident per 1,000,000 bicycle km traveled in four years leads to a 1.1% increase in cycling.
    - Lowering the risk of theft of or damage to bicycles (e.g., by providing secure parking) encourages cycling.
- An increase in the number of bicycle lanes and trails, better lighting along the roadway, and bicycle parking at destinations may encourage cycling.
- Cycling along arterial roads with on-street parking does not appear to increase cyclists' perceptions of risk.
- High amounts of automobile traffic were positively associated with increased perceptions of cycling risk.
- Bicycle facilities on straight routes with signalized junctions were positively associated with decreased perceptions of cycling risk.
- Roundabouts were associated with increased perceptions of cycling risk.
- A lack of on-road connecting facilities seems to preclude many riders from commuting via bicycle, presumably because they feel they cannot safely get to safe feeling bicycle routes.

- The presence of a bicycle lane seems to be more important in a bicyclist's choice of a bicycling route than the absence of on-street parking or the presence of an off-roadway facility.
- The results of a model built to simulate cycling preferences gave no evidence to suggest that those who cycled regularly and those who did not preferred different facilities.
- Cyclists are more attracted to shorter length trips, suggesting that an increase in direct connectivity would result in increased numbers of cyclists.
- Cyclists preferred bicycle lanes such that they would trade 4.1 minutes in a bicycle lane for each 1 minute they would have to spend in mixed traffic; for bicycle paths, the ratio was 2.8:1.
- Secure bicycle parking was identified as a significant factor in whether or not someone chose to bicycle.
- Where bicyclists are expected to share a roadway with vehicles, a study found there was a significant reduction in the number of sidewalk bicycle riders, as well as the number of wrong-way riders, after sharrows were placed on the roadway (down by 80% where sharrows were present).
- Bicyclists' perceive streets with high traffic volumes and no bicycle lanes or paved shoulders as having a very low level of service.
- One study suggests that, on average, female bicyclists are likely to perceive roadways as having lower levels of service than males; likewise, with people over the age of 40 versus their younger counterparts.
- Open-ended questions from one study revealed that the presence or absence of bike lanes was the most highly cited reason for a bicyclists grading a roadway section with a level of service "A" or "B", or "E" or "F", respectively; traffic volumes were the second most cited reason for a section's grade.

Future Research Needs

Several studies have looked at what needs to be done to strengthen the argument for bicycling facilities in cities and surrounding areas. **Krizek (2004)** examined 25 studies on the economic

benefits of bicycling facilities in order to develop an overall method for estimating them.[117] He found, however, that many factors confound the development of a comprehensive economic analysis at this time, mainly due to the tendency of transportation agencies to combine data collected for both pedestrians and bicyclists. He identified several criteria for making analyses of bicycling patterns and facilities more useful for transportation agencies, and suggested categories of benefits researchers could aim to use, as follows:

- Social transportation benefits, such as reduced congestion, improved air quality, and reduced energy consumption
- Benefits for users and non-users, measured by the degree to which bicyclists and others perceive different bicycling facilities to improve their commute or other travel routine
- User transportation benefits, measured by stated preference surveys that include trade-offs, or by examining how demand might change if a certain infrastructure package were constructed; stated preference surveys attempt to value a benefit by gauging how much people would pay to have the benefit realized, or conversely, to not lose the benefit
- Social benefits, measured by revealed preferences of households in relation to community emphasis on bicycle facilities, or estimates of the effect of bike paths and routes on home value; for example, some research on Rails-to-Trails has demonstrated a boost in the value of nearby homes
- User safety benefits, measured by bicyclist comfort with bicycling facilities (not just number of accidents)
- User health benefits, measured by the connection between the provision of bicycle facilities and increases in physical activity from bicycling; personal and community health costs can then be assigned to the findings
- Agency benefits from right-of-way preservation, which can be quantified by multiplying the probability of future use by the difference of the present cost and the net present value of future cost if the land is not preserved

Although economic analysis of this type would be helpful in making the case for more bicycling facilities along arterials, much more work in this area is needed to be able to make cogent factual

[117] **Krizek, Kevin J.** 2004. Estimating the Economic Benefits of Bicycling and Bicycle Facilities: An Interpretive Review and Proposed Methods. Transportation Research Board.

arguments, rather than strong theoretical ones. As with research on walking, it is often difficult to find a matched pair of streets, or matched sections of a street, on which to conduct bicycling research that is not confounded by differences in the variables. Three-dimensional computer modeling may provide insights into future design in this area, as well. Such computer models could simulate a bike along varying street conditions, allowing for researchers to control for possible confounders and gauge interest in or preference for certain facility types. This kind of research has just begun to be used, and offers potential for future studies. Particularly in an era of low budgets due to fiscal constraints, understanding preferences for various bicycle facilities should aid in street design and redesign to encourage more bicycling.

Gaining access to the necessary data on bicyclists' behavior and preferences, would be productive. As listed in Table 15, one of the highest priorities is to better understand the number of user trips taken per mode. Caltrans could mitigate this problem on its corridors by installing counting devices such as bicycle loop detectors at major arterial intersections. As with pedestrians, the deleterious effects of transportation barriers on discouraging bicycle activity need to be more fully understood, particularly when arterial streets act as those barriers. The studies on bicycle LOS have begun to address this problem, but more research is needed. The use of existing numbers to justify improvements should come with the caveat that current numbers that are low due to a variety of barrier effects will need to have the barriers mitigated before increases in the number of bicyclists and amount of bicycle travel can realistically be expected.

Physical Activity and the Built Environment

The Centers for Disease Control and Prevention (CDC) has linked overweight and obesity to an increased risk of hypertension, high cholesterol, type 2 diabetes, coronary heart disease, and stroke, among other serious diseases and health conditions.[118] Despite a national health objective of a lowered prevalence of obesity to 15% by 2010 (the level of obesity nationwide in 1980), obesity and overweight are on the rise: nearly 33% of United States adults are now clinically obese. Children are also being affected in record numbers: nearly 14% of 2–5 year olds are clinically obese, followed by nearly 19% of children aged 6–11, and over 17% of kids aged 12–19. Although certainly not the only factor that influences health, designing urban environments in ways that will allow for and even encourage physical activity is one way to healthier communities.

Physical activity provides the larger context for research on walkability and bikability. Many researchers have focused on the relationship between walkability, bikability, neighborhood form, and roadside design characteristics as a proxy for understanding the influences of roadside design on physical activity. Although many of these studies look at specific neighborhoods, their findings are generally applicable to Caltrans corridors where people might walk or bicycle, such as arterials lined with residential and commercial uses. This section is divided into 4 sub-sections: the relationship between physical activity and urban form; the association between obesity and built form; children and physical activity; and other physical health concerns. These have been included because they represent the most pertinent research pieces available, and give a good picture of the state of research regarding physical activity and the built environment.

The Relationship Between Physical Activity and Urban Form

A recent study by **Lee and Moudon (2008)** used GIS and behavioral survey data to examine the relationship between neighborhood form and physical activity patterns of the neighborhood

[118] United States Department of Health and Human Services. Centers for Disease Control and Prevention. http://www.cdc.gov/nccdphp/dnpa/obesity/. (Accessed February 23, 2008).

residents.[119] The researchers found that high traffic volume was the most frequently cited barrier to physical activity, followed by too much distance between desirable locations. This was true even when the data was stratified according to usual amount of physical activity. In contrast, the presence of street trees, benches, and street lighting was positively associated with facilitating walking in a neighborhood. The presence of bicycle lanes and paths, street lighting, and bicycle racks at destinations was positively associated with facilitating bicycling in a neighborhood. However, one-third of the respondents reported that their neighborhoods lacked one or more of the components that would adequately support walking. The researchers also found that the more active respondents tended to live in areas with fewer vehicular lanes, slower posted speeds, and smaller street blocks. Multivariate analysis of the data demonstrated a significant and positive association between levels of vigorous physical activity and smaller street blocks and the total number of sports-school facilities within 1 km of the home.

In **Handy's (2005)** meta-analysis of studies on travel behavior and physical activity, she also examined the relationship between physical activity and urban form.[120] She found that walking and bicycling were consistently correlated with the presence of sidewalks and a gridded street network. However, other street design variables were found to be largely insignificant in terms of influencing walking or bicycling for travel. Specific research on physical activity was often focused on specific types of physical activity and therefore produced mixed findings with regard to the design variables. This research did find a positive association between accessibility and non-home physical activity. Handy suggested that future research should focus more on defined causal relationships between specific built environment variables and specific activities, instead of looking at the general correlation between the built environment and physical activity.

The Association Between Obesity and Built Form

A **2007** study by **Frank et al.** comparing various neighborhoods and their levels of walkability found that the prevalence of obesity was lowest in the most walkable neighborhoods, and that

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[119] **Lee, Chanam**, and Anne Vernez Moudon. 2008. Neighborhood design and physical activity. *Building Research & Information* 36 (5):395-411.

[120] **Handy, Susan**. 2005. Critical Assessment of the Literature on the Relationships Among Transportation, Land Use, and Physical Activity - A Resource Paper for TRB Special Report 282. In *Does the Built Environment Influence Physical Activity? Examining the Evidence*, edited by Transportation Research Board and Institute of Medicine Committee on Physical Activity, Health, Transportation, and Land Use. Washington, D.C.

residents who lived in the most walkable environments were more likely to walk for non-discretionary purposes.[121] Using data from the extensive Strategies for Metropolitan Atlanta's Regional Transportation and Air Quality (SMARTRAQ) study conducted from 2001–2002, the researchers conducted two sub-experiments: a *neighborhood selection* study (n=2056), which looked only at those households whose tenure in residence was less than 3 years, and a *neighborhood preference* study (n = 1455), which used a representative sample of the broader SMARTRAQ survey. The researchers also used County-level tax assessor's data, aerial photographs, street network data, and Census data to create GIS maps and develop walkability indexes for the 1-km buffer around each household's residence. The land within the buffer was then categorized by use, and a walkability index was developed from the following urban form measures: commercial floor area ratio (FAR), land-use mix, net residential density, and street connectivity.

Each set of participants was surveyed to generate the data for analysis. The Neighborhood Selection Questionnaire included 10 questions regarding reasons for moving to the neighborhood; three questions (ease of walking, low transportation costs, and near to public transit) were combined in analysis to derive a load factor for "non-motorized selection." Neighborhood Preference was determined via a survey asking respondents to consider tradeoffs between living in certain places over other places. Obesity was calculated using the Body Mass Index (BMI) formulation based upon self-reported height, weight, and age data. The researchers used this information to statistically analyze the data.

The data also revealed that respondents in the least walkable neighborhoods drove significantly more than those in the most walkable environments. Regarding self-selection (the idea that people who like to walk choose more walkable places, or vice versa), the data indicated that vehicle miles traveled were significantly higher for respondents who ranked the non-motorized factors (ease of walking, low transportation costs, and near to public transit) as the least important in choosing a residence, and that obesity was most prevalent among those who prefer suburban neighborhoods, regardless of the level of walkability. On the opposite end, those who

[121] **Frank, Lawrence Douglas,** Brian E. Saelens, Ken E. Powell, and James E. Chapman. 2007. Stepping towards causation: Do built environments or neighborhood and travel preferences explain physical activity, driving, and obesity? *Social Science & medicine* 65: 1898-1914.

preferred the most walkable environments reported significantly more walk trips for both discretionary and non-discretionary travel. However, the data also revealed that those who preferred more suburban environments walked more when living in a walkable neighborhood, suggesting that the design of the built environment makes a measurable difference in residents' travel patterns. Finally, approximately one-third of residents in auto-dependent environments stated a preference for more walkable environments, suggesting an undersupply of such neighborhoods in Atlanta.

The authors caution that the results may not be representative of the entire community, as the respondents tended to be white and older. Therefore, although the results are encouraging regarding the need to create walkable neighborhoods in order to promote walking, research involving more diverse demographic groups is needed to strengthen the findings. In addition, transportation planners and engineers would benefit from more detailed analysis of the nuances of neighborhood form in future research.

In **2003**, **Saelens et al.** conducted a study looking at the effects of the neighborhood environment on physical activity. [122] The researchers mailed surveys to two neighborhoods in San Diego (one considered to exhibit high walkability and the other low walkability) to gather information about the neighborhood environment of the participants, the amount of time (in minutes) the participant spent walking during the day in the prior week, leisure time, and demographics including height and weight. The neighborhood environment variables included questions about sidewalks, bicycle and pedestrian trails, and street trees. Fifty-four participants represented the high walkability neighborhood and 53 participants represented the low walkability neighborhood. Each participant was also asked to wear an activity monitor for 7 days that could differentiate between the intensity of physical activity.

The results indicated that residents of the highly walkable neighborhood engaged in approximately 52 more minutes of moderate-intensity physical activity during the week, and were found to have a lower average BMI than the residents in the low-walkability neighborhood.

[122] **Saelens, Brian E.**, James F. Sallis, Jennifer B. Black, and Diane Chen. 2003. Neighborhood-Based Differences in Physical Activity: An Environment Scale Evaluation. *American Journal of Public Health* 93 (9): 1552-1558.

The high walkability neighborhood characteristics applicable to arterial street design included street connectivity, aesthetics, and safety from traffic. Conversely, the data indicated that a higher percentage of residents in the low-walkability neighborhood met criteria for overweight than those in the high-walkability neighborhood. Residents in the high-walkability neighborhood also reported more time spent walking for errands and during work or school breaks than the residents in the low-walkability neighborhood, indicating a possible habit-forming aspect of walking. Although walkability is influenced by many factors, this research clearly suggests that the infrastructure must be provided for the activity to occur. The research findings should be transferable, even though the sample size was fairly small (n=107) and the participant pool was 80% white, as they were consistent with previous studies.

Children and Physical Activity

With growing numbers of overweight and obese children, research efforts have focused on potential interventions for physical activity. **Tudor-Locke et al.** suggested in **2001** that relying on physical education classes in school to provide sufficient physical activity to students would fall far short of the recommended 1-2 hours of physical activity per day.[123] To supplement current efforts, they suggested a focus on active travel to school (ATS) could encourage greater amounts of physical activity. The following studies illustrate the connection between physical activity for children and ATS.

To explore the problem of weight gain in children, **Zabinski et al. (2003)** examined barriers to and support for physical activity in overweight (OV) children.[124] The researchers surveyed OV and non-overweight (non-OV) children aged 8-16 and analyzed the data to determine differences between the two groups. The data indicated that body-related barriers were the most frequently identified barriers for OV girls (indicative of self-consciousness about one's physical appearance), and that this type of barrier was significantly greater for OV girls than OV boys. OV children of both sexes also frequently reported convenience barriers (i.e., not enough time) to physical activity. In comparison with non-OV children, the OV children reported

[123] **Tudor-Locke, Catrine**, Barbara E. Ainsworth, and Barry M. Popkin. 2001. Active Commuting to School - An Overlooked Source of Children's' Physical Activity? *Sports Medicine* 31 (5):309-313.
[124] **Zabinski, Marion F.**, Brian E. Saelens, Richard I. Stein, Helen A. Hayden-Wade, and Denise E. Wilfey. 2003. Overweight Children's Barriers to and Support for Physical Activity. *Obesity Research* 11 (2):238-246.

significantly higher frequencies of 6 different barriers, with the highest frequencies for body-related, resource (i.e., lack of convenient place to do physical activity), and social barriers (i.e., not having friends to exercise with). In particular, OV girls reported significantly more body-related, resource, and social barriers than non-OV girls, while OV boys indicated only higher body-related barriers than non-OV boys. These findings suggest an opening for using travel to school as a way to increase physical activity, as it could potentially counter several types of barriers simultaneously. In addition, the findings indicate a need for provision of infrastructure for physical activity to occur.

McDonald (2007) used data from the National Personal Travel Survey (NPTS) to examine travel trends in ATS from 1969 to 2001 among U.S. children.[125] Her analysis revealed that walking was much more common than bicycling to school (90% versus 10%, respectively), and that the average round-trip time for ATS was 20–25 minutes by foot and 17–26 minutes by bike, indicating a substantial contribution to the daily physical activity quotient. However, she also found that walking and bicycling to school had declined to a historic low of 12.9% by 2001, and that elementary school children, who once walked or biked to school more than other groups of children, experienced the steepest decrease in ATS from 1969 to 2001. Some groups still use ATS more than others: boys have always walked and biked to school more than girls, and continue to do so; and minority children and children from households with incomes less than $30,000 were also more likely to walk to school.

As expected, ATS rates varied noticeably with distance to school. Living within one mile of school was associated with nearly 50% of students using ATS in 2001, as compared with less than 2% of children living 3 or more miles away. In addition, the model showed that living within one mile of school increased the odds of ATS by at least 160 times the odds of children living 3+ miles from school. However, the percentage of children within one mile of their school who used ATS dropped by nearly half from 1969 to 2001, and thus the percentage of children living within a walkable or bikable distance from their schools also declined in the same period. McDonald concluded that this change in spatial distribution of students with

[125] **McDonald, Noreen**. 2007. Active Transportation to School - Trends Among U.S. Schoolchildren, 1969-2001. *American Journal of Preventive Medicine* 32(6): 509-516.

regard to their schools may account for 47% of the total decline in ATS. She also cited traffic safety and "stranger danger" concerns as reasons for parents not allowing their children to walk or bike to school. Creating safe, accessible environments may be one way to mitigate these concerns.

Boarnet et al. (2005) examined Safe Routes 2 Schools (SR2S) programs in California to better understand the effect they had on the propensity of children to walk or bicycle to school.[126] Although the literature did not detail the SR2S implementations, many were identified as sidewalk improvements, traffic control projects, and street crossing improvements, all of which are applicable to arterial streets, and may in fact be more important for arterial streets than local streets due to traffic volumes. The survey revealed that more parents stated that their child walked or biked less after the improvements than said that their child increased rates of walking or bicycling, regardless of whether or not the SR2S project was along their route to school; the authors suggest an overall drop of active transportation to school as the reason for this finding. However, over 3 times as many children who lived on the SR2S route walked or biked post-improvement as those who did not live on the route, particularly if the SR2S project included sidewalk improvements or traffic control projects. The authors suggest that the backdrop of decreasing rates of walking to school was likely influenced by concerns over stranger danger.

Cooper et al. (2003) looked at the physical activity levels of elementary-aged children who walked or biked to school.[127] They found that children who walked to school were significantly more active during the hour from 8–9 am than those who were driven. The active travelers were also found to have significantly more moderate-to-vigorous physical activity. In particular, boys who walked to school were involved in a significantly greater amount of physical activity from the hours of 3–8 pm than those who were driven to school; this difference was not evident for the girls in the study. The active travelers did not exhibit a large difference from the non-active travelers in activity patterns on the weekend days, suggesting that the active travel to school significantly contributed to their higher physical activity levels during the week.

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[126] **Boarnet, Marlon G.**, Craig L. Anderson, Kristen Day, Tracy McMillan, and Mariela Alfonzo. 2005. Evaluation of the California Safe Routes to School Legislation - Urban Form Changes and Children's Active Transportation to School. *American Journal of Preventive Medicine* 28 (2S2):134-140.

[127] **Cooper, Ashley R.**, Angie S. Page, Lucy J. Foster, and Dina Qahwaji. 2003. Commuting to School - Are Children Who Walk More Physically Active? *American Journal of Preventive Medicine* 24 (4):273-276.

Other Physical Health Concerns Related to the Built Environment

Although this section has focused mainly on the relationship between the built environment and obesity, other physical health concerns are also important. **Koren and Butler (2006)** examined previous research to determine the "interconnection between the built environment ecology and health," and found several benefits to physical health.[128] One study showed a connection between air pollutants and asthma, a rising concern in many cities. Another study linked urban heat island effects, associated with the dark surfaces of roadways and rooftops, to an increased chance of heat stroke. Urban heat island effects have been found to contribute to urban temperatures 2–10° F higher than nearby rural areas. Other research showed that local water sources are more commonly at risk due to runoff from associated roadways. In each of these cases, trees and landscaping have the potential to mitigate harmful effects, through the interception of air pollutants, the shading of buildings and roadways, and the absorption of groundwater. In future transportation corridor designs, it is recommended that Caltrans consider these community health costs, particularly for urban roadways. The benefits of street trees for intercepting air pollution and heat radiation may need to be valued more than in the past. More information on these subjects will be covered in *Chapter V – Environmental Effects* of this review.

Summary of Key Research Findings

The following is a summary of the key findings on the research related to corridor roadside design and physical health:

- High traffic volume was the most frequently cited barrier to physical activity, followed by too much distance between desirable locations.
- Walking and bicycling were consistently correlated with the presence of sidewalks and a gridded street network.
- The prevalence of obesity was lowest in the most walkable neighborhoods in one study, and self-selection could not fully explain the variation.

[128] **Koren, H.S.** and C. D. Butler. 2006. The Interconnection Between the Built Environment Ecology and Health. *Environmental Security and Environmental Management: The Role of Risk Assessment* 111-125.

- Approximately one-third of the residents in auto-dependent environments stated a preference for more walkable environments.
- Overweight girls reported significantly more body-related, resource, and social barriers for overweight girls when compared to non-overweight girls, while overweight boys indicated only higher body-related barriers than non-overweight boys. These findings suggest an opening for using travel to school as a way to increase physical activity, as it could potentially counter several types of barriers simultaneously.
- Traffic safety and "stranger danger" concerns were significant reasons many parents did not allow their children to walk or bike to school.

Future Research Needs

The research on physical activity, neighborhood design, and obesity is complicated in part because physical health is affected by much more than exercise, and in part because the decision to exercise is multi-faceted.

- It may be impossible to conduct a study that is truly able to control for all potential confounding variables, but it seems that researchers are honing techniques to isolate the connection between physical activity and the design of the built environment. The research on children's active travel to school seems promising for shedding light on this relationship.
- Research is also needed that can quantify the physical health effects of bicycling and walking as mainstream travel modes along arterial streets. This should show effects on body mass and coronary strength, as well as respiratory health, and should look at international examples, as well as leading examples in the United States, such as Portland, Oregon, New York City, New York, and Davis, California.
- There seems to be a fair amount of research yet unpublished that examines the impacts of various types of air pollution – e.g., ozone and particulate matter – on residential populations in different areas of cities. This research will hopefully contribute to a greater understanding of how to mitigate such effects through transportation design, and should enable Caltrans to better plan its roadways through partner communities.

- It would be interesting to see a study on the effects of street trees in influencing either bicycling or walking, particularly in warmer climates. As mentioned in the previous sections, 3-D modeling seems to be a potentially useful tool in this area.

Psychological Well-being

Psychological and emotional health is equally as important as physical health, and many studies have been conducted on the psychological and emotional impacts of landscaping. Although the bulk of the research has looked at the impacts of landscaping on drivers or local residents, some research directly addresses pedestrians. The research that has been done is generally not specific to highways or arterials; nonetheless, inferences can be made. Other studies have documented the link between psychological and physical health, suggesting that the presence of vegetation positively impacts physical health in indirect ways, as well.[129]

Benefits of Viewing and Being Present in Greenspace

In a literature review of studies on the various contributions of nature toward mental and physical health, **Pretty (2004)** found a strong correlation between people viewing or being present in nature and feeling healthier.[130] He hypothesized that the known benefits of physical activity toward reducing the risk of chronic disease, when combined with the psychological benefits of interaction with nature, could produce a "green exercise" philosophy that would result in multiplied benefits for humans.

Pretty's review included other studies that have documented the benefits to humans of viewing and interacting with nature. Cooper-Marcus and Barnes (1999) reported that patients who regularly visit gardens report positive changes in mood, while Whitehouse et al. (2001) documented feelings of relaxation, refreshment, and hope in conjunction with hospitalized children and visits to a "healing garden". One study of patients at a nursing home in Texas found significantly fewer physical and emotional maladies after the installation of healing gardens, greenhouses, and atriums; in addition, the staff absenteeism rate decreased by 48% after

[129] **Pretty, Jules**. 2004. How nature contributes to mental and physical health. *Spirituality and Health International* 5 (2): 68-78.
[130] Pretty, 2004.

the installations. Ulrich (1984) compared the recovery rates of hospital patients in rooms with urban views versus natural views, and found that those viewing natural scenes experienced a quicker recovery with less medicine than patients viewing urban scenes. In other research, Hartig et al. (1991, 2003) documented the positive relationship of both viewing and being in nature with restored concentration and declining stress signs such as blood pressure.

Ulrich (1986) conducted a literature review of studies looking at aesthetic, emotional and physiological responses to various types of natural environments.[131] His findings indicate that humans have a strong preference toward nature, particularly when trees are present. As well, urban scenes appear to become more palatable when trees and vegetation are present. Natural views also seem to positively affect emotional and physiological states, suggesting that views of nature may be most beneficial for people experiencing stress or anxiety. Based on the findings of several research studies, Ulrich presented a model for determining the preference for unspectacular natural scenes, including the variables: complexity, a focal point and patterning, moderate to high level of depth that is clearly definable, even or uniform ground surface that is relatively smooth and facilitates movement, deflected or curving sightline, and absence of threat. Although the model would benefit from a more nuanced approach to both individual and cultural preferences, it can still be used to guide landscape development within urban settings, particularly along Caltrans corridors where residential and commercial uses result in the potential for much human interaction with nature.

Subjects' self-ratings of feelings before and after viewing natural and urban settings revealed positive influences on the emotional states of those viewing natural scenes. Natural scenes also sustained attention and interest better than urban views. In addition, recordings of brain activity revealed significantly higher alpha-wave amplitudes while subjects viewed trees and other vegetation in contrast to urban scenes. As a result, viewers felt more wakefully relaxed while viewing the vegetation and water scenes.

[131] **Ulrich, Roger S**. 1986. Human Responses to Vegetation and Landscapes. *Landscape and Urban Planning* 13: 29-44.

Maller et al. (2005) conducted a literature review on research that could contribute to a socio-ecological public health movement, and found evidence of many benefits to humans from interaction with nature.[132] Several studies examined the impacts on blood pressure, cholesterol, outlook on life and stress reduction from contact with nature, and found a positive effect on each of the areas. Other studies looked at the effects of viewing nature on brain activity, and found that psychological response to nature involves feelings of pleasure, sustained attention or interest, 'relaxed wakefulness', and dilution of negative emotions like anger and anxiety. In addition, while viewing nature, nervous system activity is reduced and the brain is relieved of 'excess' circulation. Natural experiences seem to be able to strengthen the right hemisphere of the brain and restore harmony to the brain functions overall.

Maller described a 1991 study by Ulrich et al., who investigated the relationship between nature and stress recovery by looking at the effects of viewing various natural and urban scenes on subjects who had just watched a horror film.[133] After measuring several vital signs and stress indicators such as heart rate, skin conductance, and muscle tension to compare recovery rates for the participants, the researchers found that the subjects viewing the natural scenes after a stressful experience exhibited a shorter and more complete recovery time than those viewing urban scenes. The natural scenes were characterized by a moderate amount of complexity, a focal point or other evident patterning, a moderate level of clearly defined depth, even or uniform texture on the ground surface, a deflected or curing sightline, and little or no perceived threat. In contrast, the urban scenes lacked vegetation and other elements of complexity and depth. The researchers concluded that viewing the natural settings seemed to elicit a response similar to the parasympathetic nervous system, aiding in restoration of energy.

In a related study, Tennessen and Cimprich (1995) tested university students in rooms with either natural or non-natural views, and examined the scores to determine correlation between the view

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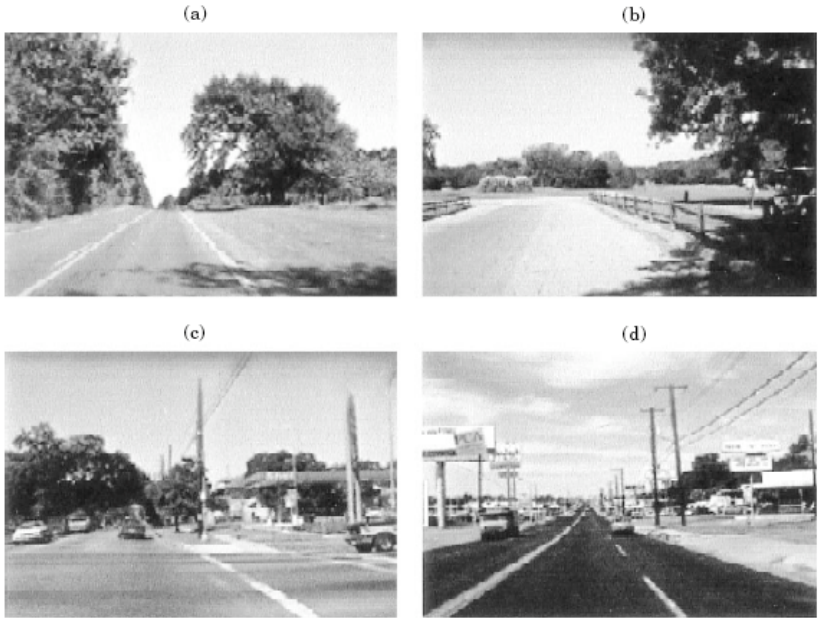
[132] Maller et al., 2005.
[133] As quoted in Maller et al., 2005:
- **Ulrich, R. S.**, Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A. and Zelson, M. (1991) Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology* 11: 231–248.

and the test performance.[134] The findings suggested that students who viewed a natural scene while taking the test performed better than those viewing a non-natural scene.

Parsons et al. (1993) examined the effects of various driving environments on stress and found a clear connection between the presence of greenery and facilitated stress recovery.[135] A total of 160 participants was divided into groups of 8-12 and subjected to a stressor 1-video-stressor 2 sequence in order to determine the difference between viewing mostly urban versus mostly natural driving scenes. The first stressor was either watching a slightly stress-inducing video or performing a slightly stress-inducing task; the video was a short videotape of a driving experience through one of four environments, illustrated by the photos in Figure 5; the second stressor was whichever of the two stress tests not yet performed.

Figure 5. Representative scenes from the four environmental 'drives'



Panels (a)-(d) show the Forest, Golf, Mixed and Urban drives, respectively.

The participants exhibited negative emotional responses and prolonged stress-recovery periods after viewing drives dominated by man-made artifacts such as utility lines, buildings, and

[134] As quoted in Maller et al., 2005:
- **Tennessen, C. M.** and Cimprich, B. (1995) Views to nature: effects on attention. *Journal of Environmental Psychology* 15: 77–85.

[135] **Parsons, Russ**, Louis G. Tassinary, Roger S. Ulrich, Michelle R. Hebl, and Michele Grossman-Alexander. 1993. The View from the Road: Implications for Stress Recovery and Immunization. *Journal of Environmental Psychology* 18: 113-139

billboards. In contrast, driving scenes through park-like areas elicited the least effect on blood pressure and promoted the quickest recovery from stress and highest scores on subject tests. As driving itself can be considered stressful or relaxing, future research would benefit from actual experience on the road or in a driver simulator, to better understand the effects of scenery on physiological and psychological states. In addition, measurements of design features would be helpful for future transportation corridor design.

Cackowski and Nasar (2003) hypothesized that exposure to highway vegetation might mitigate the anger and frustration that sometimes accompany driving.[136] To test the hypothesis, they subjected 106 students from Ohio State University in a controlled laboratory setting to a stress-video-stress sequence, beginning with intentionally distracting the students while they took a test and then giving false scoring keys for the students to grade themselves. The students then took the State Anger section of the Speilberger State-Trait Anger Expression Inventory (STAXI) so that the researchers could measure anger levels. The students then watched one of three driving videos: Built-up Highway (mostly built form with little vegetation, six lanes of traffic), Garden Highway (some parkway elements in addition to vegetation, six lanes of traffic), and Scenic Parkway (two lanes of traffic, vegetated median, heavy roadside vegetation); afterward they took the STAXI a second time. Finally, the participants were given the task of solving four anagrams – two of which were intentionally unsolvable. The researchers used the amount of time spent on the unsolvable anagrams as a proxy for the level of tolerance for frustration felt by each participant.

Although the data did not reveal any effects of viewing natural versus urban driving scenes on participants' levels of anger, it did suggest that roadside vegetation increased driver levels of frustration tolerance. The findings also suggested that viewing natural driving scenes contributed to clearer thinking than viewing built-up environments. Although future research would be more helpful if levels of traffic are controlled for or if subjects participate in actual driving scenarios instead of viewing driving scenes, these results suggest that psychological

[136] **Cackowski, Jean Marie**, and Jack L. Nasar. 2003. The Restorative Effects of Roadside Vegetation: Implications for Automobile Driver Anger and Frustration. *Environment and Behavior*. 35(6): 736-751.

factors related to crashes, such as driver frustration, should also be considered in transportation corridor design.

Based on previous studies that have shown consistently higher task performance among individuals in natural versus urban settings, **Kaplan (1995)** hypothesized that natural settings could provide the variables needed to restore the mind from *directed attention fatigue*, which occurs as a result of over-concentration during tasks that may not feel physically taxing, such as driving.[137] Such fatigue is a "key ingredient" in human error and ineffectiveness, and results in reduced ability to perceive information, comprehensively survey and understand situations, and choose direction of course. The loss of attention is thus particularly dangerous in relation to tasks where there is risk of harm -- such as while driving.

Kaplan hypothesizes that one way to restore attention is by giving the mind a break and focusing on something that provokes involuntary attention, or fascination. He identified three elements necessary for fascination: 1) the subject must shift attention to a separate environment, either physical or conceptual, 2) the environment must be rich and complex enough that it creates an alternate world, and 3) the environment must be fit what one is trying to/would like to do. In other words, one fits comfortably into this alternate environment. Natural settings easily encompass all three of these variables by providing endless patterns for fascination, a sense of extent, and an inherent compatibility (in the majority of situations) with human inclinations.

Because of the potential seriousness of directed attention fatigue while driving, this research points to a need for mind-"fascinating" roadside elements, and, based on the research by Kaplan, natural elements seem a good option. Such a fascinating roadside landscape could be found along a highway stretch with large natural elements, such as trees (e.g., the redwood forest in Northern California), and could enable drivers to pay attention more fully, for longer. There seem to be two options for designing this landscape: the first involves building the traditional concrete roadway landscape and interspacing it with dramatic stretches of natural elements to

[137] **Kaplan, Stephen**. 1995. The Restorative Benefits of Nature: Toward an Integrative Framework. *Journal of Environmental Psychology* 15: 169-182.

energize the mind once it has become tired; the second involves building longer stretches of natural landscape that should lead to a slower rate of directed attention fatigue in the first place.

In addition, this research seems to underscore the importance of providing roadside greenery along rural roads well before they transition into an urbanized "main street" location in order that any driver fatigue might be mitigated before they enter a more complex and risky driving environment where pedestrians and bicyclists may be present. Kaplan's findings also suggest that fatigued directed attention can precipitate stress, and that the presence of nature can potentially mitigate both conditions, making driving safer.

Preference for Green Space

Kuo (2003) reviewed studies that examined the connection between green space, particularly trees, and residential housing in Chicago.[138] The studies controlled for environmental features, self-selection (residents were to have been randomly assigned to apartments), and the control of landscaping (residents were to have no control), but looked at varying amounts of green cover. The data revealed that residents were more sensitive to the presence of trees than grass, but that vegetated spaces in general were much preferred over barren open spaces by all age groups. The residents tended to spend more time outside and more time socializing if trees were nearby, and children tended to play more in green areas than barren spaces. This finding is particularly important in consideration of the socio-economic status of the residents, as time spent in social activities was interpreted to increase the likelihood of making important supportive connections.

In addition, residents living near green space reported feeling safer and experiencing less disruption than those without green space. Kuo also found that proximity to green space was much more important than the size of the space – i.e., that residents would rather have a tree outside their windows than a further-away large park. These findings corroborate previous studies' findings that landscaping elements, particularly trees, can potentially benefit all those who live, work, and travel along Caltrans corridors. However, this research goes one step further

[138] **Kuo, Frances E**. 2003. The Role of Arboriculture in a Healthy Social Ecology. *Journal of Arboriculture* 29(3): 148-154.

to underscore the potential importance of landscaping and trees to situations where Caltrans roadways run through lower-income neighborhoods (as they often do in urban contexts).

Wolf (2003) examined driver preferences and perceptions of roadside landscaping in several major U.S. urban areas.[139] Using images of a wide variety of landscape treatments along freeways, ranging from a barren edge to prominent buildings to a tree screen, she surveyed a random sample of residents from the metro areas of Seattle, Washington, Minneapolis, Minnesota, Detroit, Michigan, and Baltimore, Maryland; a total of 404 responses (13.5%) were received. The results indicated that every setting with natural vegetation scored consistently higher than non-vegetated settings, and that respondents overwhelmingly preferred trees and vegetation. The results also suggested that drivers pay attention to their surroundings while driving, indicating that the presence of landscaping could potentially affect driver state of mind and even behavior. Although the sample size was small, the research findings are consistent with other studies' findings regarding human preferences toward green space. Future research would benefit from a process where drivers chose from moving, rather than still, scenes, which would more accurately mimic driving conditions.

Ulrich's 1986 literature review also suggested aesthetic preferences tend toward managed forest stands as opposed to non-manipulated settings, but do not indicate a simple relationship between aesthetic responses and the presence of built features in natural settings. Rather, preferences seem to be correlated with the degree of compatibility between the elements and their surroundings. For example, cars were identified as "non-fitting" items due to their temporary nature (i.e., they don't fit in with the surroundings). He also found a strong link between exposure to vegetation and significantly reduced feelings of fear and increased positive feelings such as affection and elation.[140] In contrast, urban scenes were associated with aggravated anxiety and increased feelings of sadness.

Landscaped scenes were also associated with driver preference, when given the choice between an urban expressway and a scenic drive. However, there seems to be a lack of clarity about how

[139] **Wolf, Kathleen**. 2003. Freeway Roadside Management : The Urban Forest Beyond the White Line. *Journal of Arboriculture* 29(3*)*. 127-136.
[140] Ulrich, 1986.

much detail drivers can perceive in the roadside environment at certain speeds (such as on freeways); evidence indicates that larger objects such as trees would be the most effective at influencing drivers' mental states, but mature trees are prohibited in certain places in established engineering standards.[141] In consideration of arterial streets with residential uses, residents in high density housing much prefer settings with greater vegetation in the fore- and middle-ground, with a particularly strong preference toward trees. They also tend to judge attractiveness of neighborhood largely by what they see from their windows, and prefer views of vegetation. However, the relationship between preference and amount of vegetation seems to be non-linear, that is, there appears to be a plateau after which more vegetation does not increase preference. Future research that can clarify this point would be beneficial to transportation corridor designers.

Summary of Key Research Findings

Much of the research reviewed was conducted in the 1980s and 1990s, and would likely benefit from an update; however, the research findings from the various studies are consistent with each other, leaving little reason to doubt the applicability of the results to current transportation corridors. The findings in this section generally suggest that the greening of Caltrans corridors, particularly those with both residential and commercial uses, may result in psychological and emotional benefits for those who live, visit, work, or travel along the roadway.

Future Research Needs

Future research should address key questions that arose from earlier studies:

- How much green space along arterials and highways is needed to provide a measurable health effect in terms of psychological well-being?
- What types of landscaping most positively affect drivers versus vehicle passengers, and how do those elements relate to the landscaping most beneficial to residents and workers along transportation corridors?
- How can roadside landscaping mitigate the risk of directed attention fatigue along highways, in contrast to blank sound walks, which may exacerbate the risk?

[141] Caltrans. Highway Design Manual. Chapter 900.

CHAPTER IV: COMMUNITY ECONOMIC VITALITY EFFECTS

In most places, the streets are the arteries of the city or town: they carry people—the life of the community—from one place to another. Small towns may only have one "main street" running through them, and these streets often serve as both through arterials and local shopping streets. In larger towns and cities, there are usually multiple arterial throughways, some lined with commercial uses, others with residential uses, others with a mix of both. Urban arterial streets are not just the way to get to a destination; for people living in a community they are often the destination itself.

This chapter reviews recent research that is relevant to the question of what impacts corridor roadside design elements can have on the economic vitality of commercial and residential areas of a community. Most of the relevant research has focused on the economic impacts of trees and landscaping. Little of the research has focused directly on urban arterial streets, but it is nonetheless possible to glean from it some understanding of the potential benefits of trees and landscaping along arterial roadsides.

The chapter covers three subject matters: the effects of landscaping on commercial rent and activity; the impacts of trees on residential preferences; and downtown pedestrian improvements.

Effects of Landscaping on Commercial Rent and Activity

Laverne and Winson-Geideman (2003) examined the influence of trees and landscaping on rental rates at 85 office buildings in Cleveland, Ohio.[142] The researchers used office rent data from Grubb & Ellis, a national commercial real estate brokerage firm, along with visual analysis, to grade each site for the following variables: visual screening, noise attenuation, shade to parking areas, shade to buildings, space definition, recreational enhancement, and aesthetics. Scores were given on a four-point scale, and the data was run in a regression model, along with the annual rent/sq. ft., to determine the effects of the various landscaping elements on the office rents. Their findings indicated that landscaping with "good" aesthetic value (the highest rating

[142] **Laverne, Robert J.** and Kimberley Winson-Geideman. 2003. The Influence of Trees and Landscaping on Rental Rates at Office Buildings. *Journal of Arboriculture* 29 (5):281-290.

for the category: "trees and landscape plants offer color, texture, and variety throughout the seasons in interesting designs") added approximately 7% to average rental rates, and that building shade over 25% provided by landscaping added another 7% to the rates. However, places where trees screened more than 50% of "objectionable views" from the ground level were found to have rental rates decreased from the average by 7%, most likely due to the need for businesses to be seen by the public.

Although the research seemed to indicate an overall net benefit to commercial buildings with landscaping, future research that used more objective measures, such as GIS aerial photo data to assess the percentage of vegetation, would be even more helpful. In addition, contextual data, such as the type of neighborhood in which the businesses were located, and the proximity to housing, transit, and freeways, would likely contribute to a more complete understanding of the impacts of landscaping on the rents. It is probable that business owners and residents along arterials and main street highways would desire landscaping and tree planting for the potentially higher rents associated with the amenities of shade and aesthetics.

Wolf (2004) looked at Athens, Georgia, a National Main Street program pilot city and a university town with an average-sized central business district (CBD), to understand the relationship between an urban forest located near the downtown business district and consumer preference.[143] She collected preference data via 365 consumer surveys distributed at the downtown commercial district over 24 separate 2-hour periods. The survey consisted of 20 color photos of streets in Athens' CBD, which were representative of typical views visitors would see; the scenes ranged from being devoid of vegetation, to containing mid-size street trees planted at equidistant intervals, to street trees forming a dense, overhead canopy. Image content known to confound viewer response, such as visually prominent people or cloud formations, was avoided; architectural features were fairly consistent in type and quality (one to three stories tall with storefronts adjacent to sidewalks). Respondents were asked to rate the images using a using a Likert preference scale (1: like the least; 5: like the most)

[143] **Wolf, Kathleen L.** 2004. Trees and Business District Preference: A Case Study of Athens, Georgia, US. *Journal of Arboriculture* 30 (6):336-346

Data analysis involved calculating the rating averages for each photograph and the combined rating means for three categories of scene types: dominant building (no trees; well maintained buildings having a historic character), buffered building (a few trees; physically larger and more simplistic buildings) and green streets (many street trees; buildings noticeable). The results revealed that the highest ranked photographs consistently had a great tree presence, with higher response values associated with larger trees and increased presence. Conversely, the lowest ranked images contained only man-made structures. The data also suggested that landscaping in conjunction with well-maintained buildings positively affected consumer judgment. In an open comment section, over 25% of the 365 respondents commented on the benefits of trees, and over 18% of the respondents requested additional trees in the area. These findings suggest that "the urban forest may be the streetscape equivalent of interior store atmospherics," and that retailers would benefit from greater attention to landscaping where possible.

In a separate study, **Wolf (2004)** evaluated potential shoppers' and business people's preferences and perceptions of trees in inner-city business districts.[144] After identifying several inner-city neighborhood shopping streets undergoing revitalization in cities across the U.S., she administered a survey to two groups of people: owners or managers of businesses along these streets and residents living in nearby areas. A total of 3,500 surveys were mailed: 2,500 to residents and 1,000 to business owners or managers, resulting in 270 completed surveys received back from the first group (12% response rate) and 179 from the second group (19% response rate after controlling for those that were undeliverable).

The survey included 32 black and white photos depicting retail environments with different street tree characteristics (no trees, formally planted trees, informally planted trees, etc.). Building height (1 or 2 stories), the tidiness of the scene, and the prominence of people in the scene were consistent across the photos. Half the photos were from a driver's perspective, the other half from a pedestrian's perspective, and the photos were grouped into five categories with varying degrees of vegetation. Respondents were asked to rate the photos on a scale of 1 (no preference) to 5 (high preference). The survey also included attitude questions and background

[144] **Wolf, Kathleen**. 2004. Nature in the Retail Environment: Comparing Consumer and Business Response to Urban Forest Conditions. *Landscape Journal* 23:1–14.

questions related to the respondents' demographics and their shopping habits (specific to residents) or their business size, character, and market focus (specific to business owners).

The data analysis revealed that the combined lowest preference score went to the "sparse vegetation" category, while the highest preference score (mean: 3.65) went to the "formal foliage" category. Business owners/managers consistently rated the scenes lower than the residents did, although no suggestions are given as to why; perhaps due to the cost of maintaining landscaping. However, if patrons prefer to shop in areas with landscaping and trees, as Wolf's previous study showed, it is likely that, knowing this, the business owners would consent to and even encourage such elements. According to the data regarding the benefits and annoyances of street trees, a one-point difference exists between the averages of the highest vegetation and the lowest, indicating that additional landscaping does impact preferences. Both sets of respondents overall gave higher ratings for benefits than for annoyances, which is consistent with the findings of residential street-tree studies.

Wolf (2005) also looked specifically at the relationship between urban forestry and main street business districts in a variety of large cities, including Los Angeles, California; Washington, D.C.; Chicago, Illinois; Portland, Oregon; Pittsburgh, Pennsylvania; Austin, Texas; and Seattle, Washington.[145] In each place, she mailed surveys aimed at measuring visual quality, place perceptions, shopper patronage, and product pricing. Using photo imagery, the survey sought to gauge preferences through both a Likert Scale and the contingent valuation method. The response rate was 12% (n=270), which the researchers attributed in part to the difficulty of contingent valuation studies, and in part to the lack of interest in urban trees by the respondents.

The findings indicated that image preference ratings increased steadily with the presence of trees. As compared to photos with well-kept buildings, the images with well-tended, large trees scored the highest – even when the trees obscured the buildings. This finding suggests that campaigns to preserve buildings in the name of business improvements should consider more investment in landscaping and tree planting. In addition, the most highly preferred business streetscapes had

[145] **Wolf, Kathleen**. 2005. Business District Streetscapes, Trees, and Consumer Response. *Journal of Forestry*. December:396-400.

ratings comparable to those of forested and outdoor recreation areas. Although business owners are often wary of trees due to the potential to block signage, the surveys indicated that openly pruned trees were valued along the same lines as those with dense canopies, suggesting that pruning for street level visibility could maintain the value of the trees to the shoppers.

In addition, the survey responses indicated a clear valuing of the trees in terms of their amenity and visual quality. The presence of trees seemed to engender positive judgments about maintenance, even when compared to other well-maintained places. In addition, the presence of trees seemed to reflect well on the merchants and the value and quality of the products. In general, the respondents indicated a willingness to travel greater distances, visit more often, and pay more for parking at locations with trees versus locations without them.

Last, the survey results revealed a higher value for all types of goods – convenience, shopping, and specialty – in business districts with trees, in both small and large cities. The amenity margin associated with trees was 12% for large cities and 9% for small cities when standardized across all categories and scenarios. Wolf acknowledged that exogenous factors, such as the local economy could also cause the price differential. However, overall, the results indicated a net benefit for business owners willing to maintain trees near their properties. For businesses located along roadways, this likely translates into the maintenance of street trees – a factor that should be considered for arterials and main streets through commercial districts.

Impacts of Trees on Residential Preferences

In order to better understand the value of street trees to communities, **Gorman (2004)** surveyed residents of State College, Pennsylvania, about their feelings regarding the street trees in their neighborhoods.[146] He targeted two groups within a sample of the permanent residents of the town: one with trees directly in front of their homes (n=977), and one with trees near their homes (n=1,023); 676 completed surveys were obtained, for a 36% response rate. Of those, 568 respondents (84%) had a tree directly in front of their residences and 108 respondents (16%) did not. The survey respondents were approximately split between genders, and covered a range of

[146] **Gorman, James.** 2004. Residents' Opinions on the Value of Street Trees Depending on Tree Location. *Journal of Arboriculture* 30 (1):36-44.

ages. The majority of the respondents had a high level of education (85% had at least a college degree) and lived in a house (84.8%; 10% lived in an apartment, and 3% in a condominium). Over 50% had lived longer than 10 years at their address, while 22% had lived at their address for 4-10 years, and 20% for 1-3 years. The survey asked questions on a four-point scale regarding the trees and whether they were positively or negatively valued.

The data analysis indicated significantly positive features for the trees, including shade, aesthetic qualities, flowers, and contribution to increased neighborhood livability and property values. There were also significantly negative features, such as the tendency for branches to break power lines during storms, roots to damage the sidewalks, and the trees to block visibility, but over 91% of all respondents classified street trees as being of great benefit, with nearly 93% of those with street trees directly in front of the home reporting such. In addition, nearly 62% of the respondents indicated that they would be willing to volunteer to help maintain the street trees in their neighborhood, suggesting a "willingness to pay" in terms of labor for the upkeep of the trees. The tree planting program in State College has been operational for many years and may have therefore biased the results due to apparently consistently high quality levels of tree maintenance, but this should not be interpreted as a reason not to apply this research elsewhere; instead, it should be seen as a standard that other communities should strive toward. In addition, although this research was clearly conducted in an exclusively residential area, the findings could be applicable to any place where residential uses occur, including along arterial roadways and in downtown areas.

Downtown Pedestrian Improvements

Whitehead et al. (2005) examined the impact of urban quality improvements on economic activity in Manchester, England.[148] Using land-use/transportation modeling software, the researchers attempted to understand how distinct groups of customers, clients, and residents would react to changes in urban quality such as creating more walkable places. They measured willingness to shop, do business, or work in areas both before and after the addition of walkable

[148] **Whitehead, Tim**, David Simmonds and John Preston. 2005. The Effect of Urban Quality Improvements on Economic Activity. *Journal of Environmental Management* 80.

improvements. Previous research has found an increase in the foot traffic of pedestrianized retail areas by 20-40%, and an increase in retail rents by 22%. Whitehead et al. found that adding urban quality improvements that promote pedestrian activity will have small but significant positive effects on workers and businesses and a small but positive impact on retail activity and rents, but a marginally negative impact on total city center employment (due to potential increased vehicular congestion in the city center). The last finding could likely be mitigated by traffic management strategies such as congestion pricing, but if that were the case, much more access by foot, bicycle, and bus would need to be provided, as was done in London. Overall, these findings provide encouraging evidence that pedestrianization can benefit all sectors of the community.

Summary of Key Research Findings

The following is a summary of the key findings on the research related to corridor roadside design and community economic vitality effects:

- There is a dearth of research related to the impact of corridor roadside design on economic vitality effects;
- At the same time, all the research that exists seems to show that roadside trees are associated with higher property values and are positively valued by the general community.

Future Research Needs

There is a need for case studies specifically associated with the impacts of corridor roadside design elements on land and property values, for example:

- Case studies of parallel streets, residential and commercial, both with and without trees and other roadside planting;
- Case studies of different parts of the same street, with and without trees;
- Studies of stretches of rural arterials, with and without regular tree plantings.
- As an example, South Van Ness Avenue, which runs through San Francisco's Mission District, does not have street trees, while Folsom Street does. They are very similar

streets in many places, and carry similar amounts of through traffic. Studies of the values of houses along each street would be useful.

There is also a need for research investigating whether or not increased pedestrian traffic due to improved pedestrian activities along an urban arterial street has any effect on the sales activity of businesses along that street or the rent value of commercial spaces. In addition, the concept of an informal "bike economy" is emerging in Portland, Oregon, where businesses are beginning to locate on bike-friendly streets. This should be studied and quantified.

CHAPTER V: ENVIRONMENTAL EFFECTS

Much research has been conducted on the various environmental benefits that accrue from trees and other greenery in urban areas. The research studies summarized in this chapter have found that urban trees and landscaping contribute to emissions and energy-use reduction, stormwater retention and filtration, air pollution interception and mitigation, and heat island mitigation. Given the crisis of global climate change, it is incumbent upon cities to look for every way to reduce environmental degradation, and using the public realm to further this goal makes considerable sense. Because streets make up the bulk of the public realm in most cities, it is important to understand how street right-of-ways can be designed to maximize positive ecological effects. Incorporating trees and other greenery into urban roadsides wherever possible, and in accordance with local bio-climatic contexts, seems a clear first step, including along urban arterials. In addition, landscaping along highways can help capture pollution emitted from the vehicles that travel along them, as well as act in a drainage capacity for stormwater.

This chapter reviews the recent environmental literature related to the environmental effects of urban greenery, particularly trees. It is divided into four sections: energy use and the urban heat island effect; stormwater interception and soil retention; air quality improvements; and extended material life. These categories are used to help organize the literature review, but it should be noted that many of the studies do not fit cleanly into one category, given that many of the studies examined multiple areas. These studies often provide monetary values for cities' evaluation, as well.

In order to limit the scope of the literature review, separate pieces on the maintenance costs of urban trees or costs associated with the potential for trees to emit volatile organic compounds (VOC's) are not reviewed here, although some of the research includes such costs in its analysis. In addition, such costs can often be mitigated by appropriate tree choice.

Reduced Energy Use and Urban Heat Island Effect

McPherson et al. (2002) examined trees in Western Oregon and Washington in order to determine their potential to improve the local environmental quality, conserve energy, and add value to their communities.[150] The researchers categorized the trees into a variety of categories based on size, which was dictated by tree height, crown volume, and leaf surface area (LSA). Prices were assigned to different costs and benefits based on local estimates. Benefits included heating/cooling, energy savings, air pollution absorption, and stormwater runoff reduction; costs included planting, pruning, removal, irrigation, infrastructure repair, and liability. The results of this study were reported in terms of annual values per tree planted; mortality rates were also included. Periodic costs such as pruning and tree removal were factored in as an average annual cost. Other costs were predominately based on findings of other literature and local surveys. Total costs and benefits were calculated based on the summation of annual costs and the summation of annual benefits.

The researchers also sought to determine where residential and public trees should be placed in order to maximize their cost-effectiveness, and which trees would best minimize conflicts with utility lines, sidewalks, and buildings. Residential trees refer to those trees on private residential property; public trees refer to trees in the public realm such as along public roadways and in public parks. Table 16 shows the chart developed by the researchers to illustrate the annual net benefits of planting trees after taking into account the costs of maintenance; the numbers assume a 20-year old tree located opposite a west-facing wall. Table 17 presents the findings from a similar study for groups of street trees based on 40-year total benefits and costs.

Table 16. Annual Net Benefits of Trees on Residential Streets

Small Tree		**Medium Tree**		**Large Tree**	
Private	Public	Private	Public	Private	Public
$11.73	$5.22	$29.16	$23.30	$51.46	$46.82

[150] **McPherson, E. Gregory**, Qingfu Xiao, Scott E. Maco, Ann Marie VanDerZanden, James R. Simpson, Neil Bell, and Paula J. Peper. 2002. Western Washington and Oregon Community Tree Guide: Benefits, Costs, and Strategic Planting. Center for Urban Forest Research. USDA Forest Service, Pacific Southwest Research Station.

Table 17. Net Benefits of Street Trees over a Forty-year Period

50 Large Trees	30 Medium Trees	20 Small Trees	100 Tree Total
$110,352	$29,556	$3,176	$143,084

The researchers classified "small" trees as approximately 28 feet tall, with a 25-foot spread and leaf surface area (LSA) of 1,891 sq. ft. "Medium" trees were classified as 38 feet tall, with a 31-foot spread and LSA of 4,770 sq. ft. "Large" trees were classified as 46 feet tall, with a 41-foot spread, and LSA of 6,911 sq. ft. The limitation of this research is mainly that some benefits are complicated to quantify. The authors mention that climatic variation throughout the research area makes it difficult to be accurate when estimating some of these benefit as well as cost values. Additionally, not all trees that are able to thrive in the western Washington/Oregon areas are completely represented, and the subjective values associated with aesthetic benefits render that category less robust than others. However, overall this piece represents a solid step forward in the process of estimating the costs and benefits of the urban forest.

Heisler (1974) reviewed literature studying the contribution of street trees to the regulation of the urban microclimate.[151] He found that shading provided by the trees lifts a significant cooling burden off of humans and structures, such that to replace the cooling, five average room air conditioners would need to run for 20 hours per day. In addition, shading only minimally influences air temperature, but greatly influences solar radiation shielding, which is a large part of what humans actually feel. Depending on crown density, various trees allow only 2-40% of solar penetration. In contrast, although parking lots absorb a similar amount of solar radiation, they store the energy, which then raises the surface temperature and heats the air above it. Heisler concludes that streets are ideal places for urban trees due to the evaporative cooling and shading benefits, as well as the shielding of people from long-wave radiation from nearby buildings.

These findings underscore the importance of shade trees for two main reasons. First, there is a general need for shade from the sun's rays as people walk along the sidewalk, such as along arterial roadways and main streets. Second, in urban areas where the pavement and the buildings

[151] **Heisler, Gordon M**. 1974. Trees and Human Comfort in Urban Areas. *Journal of Forestry*, August:466-469.

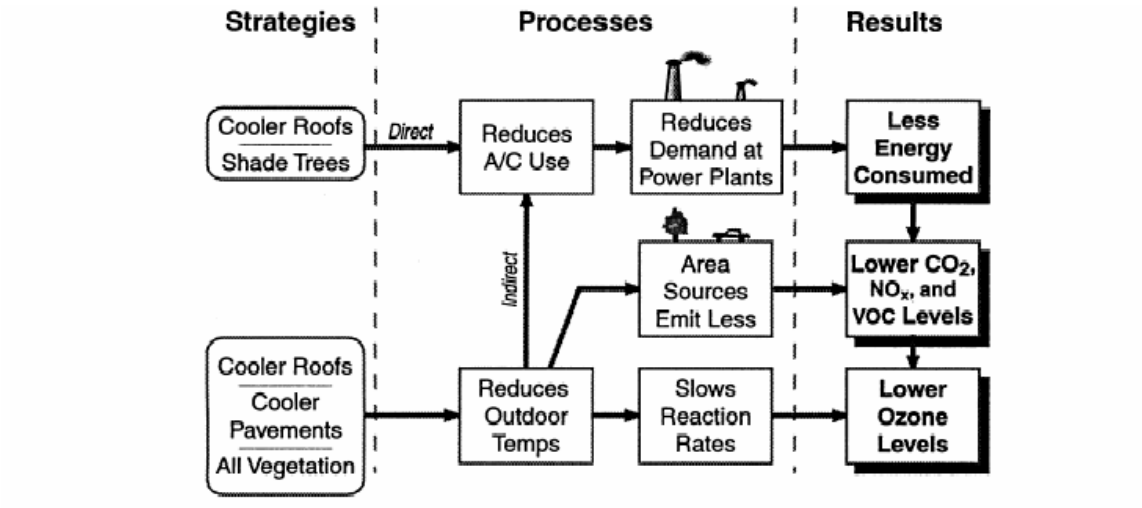
consistently absorb and re-radiate heat, the trees are necessary both to protect the pedestrians from the re-radiation and to reduce the amount of absorption overall.

Akbari et al. (2001) modeled the effects of urban heat islands on elevated summertime temperatures and corresponding increased energy usage in ten large US metropolitan areas.[152] The models examined trends in temperature fluctuation from the last 100 years in Atlanta, Georgia; Chicago, Illinois; Los Angeles, California; Fort Worth and Houston, Texas; Miami, Florida; New York City, New York; Philadelphia, Pennsylvania; Phoenix, Arizona; and Washington, D.C. To conduct their analysis, the researchers used multiple simulation models: the Department of Energy-2 (DOE-2) building energy simulation model was used to determine energy usage and energy savings in buildings; the Colorado State University Mesoscale Model was used to determine the impacts of large-scale increases in vegetation; and the Urban Airshed Model was used to simulate impacts on air quality. Energy savings from both direct and indirect sources were accounted for in the DOE-2 model.

The analysis revealed that temperatures have increased in urban areas by about 0.5–3.08°C (1–6°F) since 1940. Because electricity demand in cities typically increases by 2–4% for each 1.8°C (3–3.5°F) increase in temperature, the researchers estimate that 5–10% of the current urban electricity demand is cooling energy to compensate for the temperature increase. Increased temperatures are particularly problematic in places where smog formation is likely, such as in Los Angeles, California. However, urban trees and high-albedo (light-reflecting) surfaces have been found to offset or reverse the heat island effect. Using the DOE-2 building energy simulation, the researchers looked at direct and indirect energy savings, as illustrated in Figure 6.

[152] **Akbari, H.**, M. Pomerantz and H. Taha. 2001. Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas. *Solar Energy* 70(3): 295-310.

Figure 6. Methodology to analyze the impact of shade trees, cool roofs, and cool pavements on energy use and air quality (smog)



The researchers also looked at the study by Taha et al. (1996), which found that the addition of large numbers of trees to the urban realm should result in an air temperature reduction of 1-3°C (~ 2-6°F) in the hottest areas. Table 18 lists the reduction in air temperature for several of the largest U.S. cities.

Overall, Akbari et al. estimate that mitigation of the heat island effect via these strategies could potentially reduce national air conditioning usage by 20%, with a corresponding savings of over $10 billion per year in energy use and improved urban air quality. Although the assumptions in the model are not well-explained, this piece clearly demonstrates the importance of trees to the urban area with regard to mitigating the urban heat island effect.

Table 18. Number of additional trees planted in each metropolitan area and their simulated effects in reducing the ambient temperature. (Source: Taha *et al.*, 1996)

Location	Millions of additional trees in the simulation domain	Millions of additional trees in the metropolitan area	Max air temperature reduction in the hottest simulation cell (°C)
Atlanta	3.0	1.5	1.7 (2.5-3.5°F)
Chicago	12	5.0	1.4 (2.5-3.5°F)
Los Angeles	11	5.0	3.0 (5-7°F)
Fort Worth	5.6	2.8	1.6 (2.5-3.5°F)
Houston	5.7	2.7	1.4 (2.5-3.5°F)
Miami	3.3	1.3	1.0 (1.5-2°F)
New York City	20	4.0	2.0 (3-4°F)
Philadelphia	18	3.8	1.8 (2.5-4°F)
Phoenix	2.8	1.4	1.4 (2.5-3.5°F)
Washington, DC	11	3.0	1.9 (3-4°F)

Scott et al. (1999) conducted a study on the effects of tree cover on parking lot microclimate and vehicle emissions in Davis, California.[153] The researchers examined aerial photographs to measure parking lot surface area and amount of tree cover; one corner of the parking lot (40% of the lot) was shaded by trees, and detailed analysis showed that 8% of the total surface area of the lot was shaded. They identified the tree species through fieldwork, and tree height, crown height, crown diameter, bole height, and diameter at breast height (dbh) were determined using routine biometric techniques. The researchers used fixed automated weather stations to gauge the temperature of one shaded and one unshaded parking stall over 2 separate 5 or 6 day summer periods, which they calibrated with temperature readings taken during the same periods at a weather research station control site. They also used measurements from 55 transect walks, gathered through hand-held instruments that estimated spatially averaged air temperatures in the shaded and unshaded areas of parking lot.

[153] **Scott, Klaus I.**, James R. Simpson, and E. Gregory McPherson. 1999. Effects of Tree Cover on Parking Lot Microclimate and Vehicle Emissions. *Journal of Arboriculture* 25(3): 129-141.

On one day, the number of vehicles parked in the shaded area of the lot were tallied according to the relative amount of vehicle surface area in shade (1–25% shaded; 25–75% shaded; 75–100% shaded). In addition, two identical vehicles were parked in the lot, one in a shaded area and the other in an unshaded area, and measurements of the interior cabin and fuel tank temperatures were taken during the same times as the weather station measurements. To measure air pollution, the researchers used models known to estimate vehicle hydrocarbon (reactive organic gases, or ROG) and nitrogen oxide (NO_x) emissions during operating cycles including startup, idling, city and highway driving, and cool-down (estimations were only done for passenger cars and light-duty trucks). An emissions model was run for the actual parking lot site, and then 3 hypothetical emissions models were run: 8% parking lot shade (estimated typical county wide parking lot tree cover), 25% shade, and 50% shade.

The research findings indicated a clear connection between the presence of shade and the temperature of both the parking lot paving and aboveground air, as well as the interior cabin of the automobile. Although the shaded area of the parking lot was warmer than the control site (an area of irrigated turf near the UC Davis campus) for parts of each day, the unshaded area was warmer nearly the entire duration of the experiment. The air temperature of the shaded site was approximately 1.3°C (2–3°F) cooler than the unshaded site during the hottest period of the warmer days of the experiment, whereas the pavement temperature was nearly 20°C (36–40°F) cooler during that same time period. During periods of maximum user choice for parking, a clear preference was seen toward parking in the shade, suggesting that greater tree coverage would be welcomed by drivers parking cars.

Emissions modeling indicated that shaded areas released 3% less emissions than unshaded areas of parking lot in a scenario based on low tree coverage. The hypothetical 50% tree coverage scenario reduced emissions by an additional 2%, for a total reduction of 5%. Although this data pertains to parking lots, it should be applicable to parts of Caltrans roadways that can be shaded by street trees, such as parking spots along arterials and main street highways. In addition, the tree shade should also foster cooling on the roadway and thus contribute to a reduced urban heat island effect and perhaps longer material life of the roadway.

Souch and Souch (1993) looked at the effect of trees on summertime below canopy urban climates in Bloomington, Indiana, in order to understand the effects of varying tree species, physical characteristics, and varying environments on the overall impact of the tree.[154] The researchers measured 44 trees in the urban area of Bloomington to determine effects on air temperature, relative humidity, and vapor pressure over a 15-day period in August of 1991. The trees were grouped into 5 categories: 1) Sugar Maple individuals over grass; 2) Sugar Maple individuals along streets (over concrete); 3) Sugar Maple clumps of trees over grass (3–4 trees defined a clump); 4) Black Walnut individuals over grass; 5) Pin Oak individuals over grass. The trees were all mature and relatively similar in canopy spread. The mean tree height of each group ranged from 49–75 feet; the mean canopy radius ranged from 17.5–25 feet. Researchers took 3 sets of readings each day (morning, afternoon, and evening) to gauge the relative humidity, air temperature, and vapor pressure at the edge of and underneath each tree canopy, and compared these with readings obtained from a control site of turf without trees.

The data revealed that all trees were significantly cooler than the control site by midday, except for the street trees, which were only slightly cooler. Evenings, however, exhibited slightly warmer temperatures underneath all trees, with walnut trees over grass and sugar maple trees over concrete being significantly warmer, due most likely to longwave radiation being reflected back and forth between the trees and the ground. Relative humidity measurements showed that through midday and evening, the area under the trees had significantly higher humidity rates – 27–33% – than the open space. Vapor pressure was shown to decrease in all areas throughout the day, significantly so underneath the trees as the stomata close in the evening.

Higher temperatures were uniformly observed at the edges of the trees in comparison to underneath the canopies, and the significant cooling observed underneath the trees was not observed at the canopy edge. The edges of the street trees were always found to be warmer than the reference site, due to tree edges being over concrete versus the grassy open area. Both relative humidity and vapor pressure were found to be significantly enhanced around, not just under, the trees, although greater variability was found at the tree edges.

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[154] **Souch, C. A.** and C. Souch. 1993. The Effect of Trees on Summertime Below Canopy Urban Climates: A Case Study Bloomington, Indiana. *Journal of Arboriculture* 19 (5):303-311.

No significant correlation was found between reduced temperature and individual tree characteristics, and no significant temperature differences were found between clumped trees and individuals. However, the trees growing along streets were found to be warmer than trees growing alone or in clumps. This seems to indicate that trees should be planted over grass wherever possible to realize the greatest benefit from temperature reduction, including usage in bioswales and landscaped medians in urban areas. It should not, however, be taken as evidence that street trees do not serve an equally important purpose of shading humans, buildings, and otherwise unshaded pavement that contributes to the urban heat island effect. There is also potential to maximize benefits for paved surfaces using pervious surface materials that may allow grass to grow along with paving.

In a related study, **Streiling and Matzarakis (2003)** looked at the effects of single trees and clusters of trees on the bioclimate of an urban park location in Germany.[155] The researchers measured temperature, wind velocity, wind direction, and short- and longwave radiation. They used these measurements to then calculate vapor pressure, relative air humidity, mean radiant temperature, and physiologically equivalent temperature. Nitrogen oxides and ozone were measured using discoloration of filters; volatile organic compounds (VOC's) were calculated using a sorption material that was then desorbed and analyzed. The trees examined were all horsechestnut trees, varying in size.

The researchers found that as the number of trees in an area increased, the temperature decreased; on average, air temperature under a single tree is 0.1°C (0.5°F) higher than the temperature detected under the cluster of tree crowns. In addition, mean relative humidity was 5–7% higher in the areas with trees than without, while the difference between a single tree and a cluster of trees was approximately 1%, with the cluster showing a higher relative humidity. Human comfort as measured by the physiologically equivalent temperature (PET) thermal index indicated a much more accommodating temperature in the areas with trees than without. The trees were also shown to reduce nitrogen oxides by 45% and ozone by 55% on the days measured.

[155] **Streiling, S.** and A. Matzarakis. 2003. Influence of Single and Small Clusters of Trees on the Bioclimate of a City: a Case Study. *Journal of Arboriculture* 29 (6):309-316.

Although these results seem to quantify something felt by most pedestrians, that trees contribute to human comfort, future research that looks at several varieties of trees and a larger overall sample size would be even more helpful. However, this research still contributes to the evidence that street trees along arterials likely enhance human comfort, particularly in urban areas where people routinely walk underneath their shade.

Simpson (1998) looked at residential and commercial spaces in regional Sacramento to determine the savings costs for cooling and heating from the urban forest.[156] In order to determine impacts by trees, he examined energy use in different types of residential and commercial spaces throughout the county. He broke this information down to energy use per conditioned floor area (CFA), which is also known as unit energy density (UED). This metric was then investigated through various density types: single-family homes (low density), 2–4 unit residential (medium density), and 5+ unit residential (high density). Commercial buildings were categorized based on size. Next, alterations of UED were observed based on changes in solar radiation, air temperature, and wind speed. It was expected that these three categories would be affected by the presence of trees.

The background for this research required an accurate database of tree and building data. Housing data was accessed through the 1994 Sacramento Area Council of Governments (SACOG) information. Tree density was determined based on number of existing trees per unit (trees per unit was defined as trees within 66 feet of the structure). Tree canopy and building cover were determined by the percentage of surface area covered by buildings or vertical projection of tree crowns; energy costs were determined based on average rates per typical buildings of the above classifications. Based on this information, Simpson quantified the effects of energy use changes in both energy units and dollar units. Results are broken down into categories based on changes of climate as well as building typology.

His analysis of the county's 6 million trees revealed that 3.5 million grow on residential and commercial land, and of these 3.5 million, 32% had shading ability (grow within 66 feet of a

[156] **Simpson, James.** 1998. Urban Forest Impacts on Regional Cooling and Heating Energy Use: Sacramento County Case Study. Journal of Arboriculture 24 (4):201-214.

structure). The total energy estimates used for space conditioning (climate control/ humidity control) for the county with and without trees are presented in Tables 19-21.

Table 19. Total County-Wide Energy Usage for Space Conditioning

	Annual Cooling	Peak Cooling	Annual Heating
Without Trees	1,439 GWh	2,037 MW	20,277 TJ
Change With Trees	-157 GWh (10.9%)	-124 MW (6.1%)	+ 145 TJ (0.7%)

Table 20. Total County-Wide Change in Cost due to *Shading*

Change in cost of cooling	Change in cost of heating
- $10.7 million	+ $5.6 million

Table 21. Total County-Wide Change in Cost due to *Wind Speed Reduction*

Change in cost of cooling (less evaporative cooling)	Change in cost of heating
+ $3 million	- $7.2 million

Based on these estimates, Simpson concluded that the urban forest of Sacramento County saves approximately $20 million through shading and reduction of wind speed and air temperature. Approximately $18.5 million of the total is saved due to reduced cooling costs, while the remainder is saved due to reduced heating costs. Although this piece looked only at Sacramento, it formed the basis for the more recent research study by McPherson and Simpson, reviewed below.

McPherson and Simpson (2003) looked at 21 cities across California to determine the potential energy savings to buildings through an urban tree-planting program.[157] Using aerial photography, the researchers categorized the land areas within the 21 cities according to their land uses, proportion of land covered by tree coverage, city size, and average tree crown projection area. In addition, because of California's varying climate, the state was divided into 11 climate zones. Further calculations were then completed on the city level in order to provide

[157] **McPherson , E. Gregory** and James R. Simpson 2003. Potential Energy Savings in Buildings by an Urban Tree Planting Program in California. *Urban Forestry and Urban Greening* 2:73-86.

adequate input information for computer simulations, which would then be able to determine the relative effects of tree shading on energy usage.

Estimated costs for electricity were based on estimated 2001 prices from California's energy purchasing strategies and contracts. The present value of benefits (PVB's) from heating and cooling savings were calculated assuming a 5% nominal discount rate for a 15-year planning horizon (2001–2015). (The 15-year planning period was deemed a compromise between the short-term financial and political need for return-on-investment and the long-term life span of trees.)

The data revealed that California's 177 million energy-conserving urban trees reduce annual electricity use for cooling by 6,407.8 GWh (2.5% of the total energy usage). This reduction provides a wholesale savings of approximately $485.8 million to utilities, and about twice as much ($971.6 million) to customers. The researchers estimated that planting 50 million trees to shade east and west walls of residential buildings would produce a total cooling savings of 46,891 GWh, or $3.6 billion, after 15 years. It would also offset 60% of the increased electricity consumption associated with California's projected 8 million new residents.

Although this research only deals with residential buildings, energy savings to commercial establishments would likely be substantial, as well. In addition, the detailed data on the energy saving benefits of urban trees in all major climatic regions of California possibly provides data for Caltrans and its partner communities throughout the state to use in models evaluating urban street tree benefits.

Hydrology: Stormwater Interception and Soil Retention

McPherson's (1992) conducted a study that focused on accounting for the benefits and costs of urban greenspace in Tucson, Arizona.[158] To conduct his analysis, McPherson reviewed traditional accounting methods and used them to develop a greenspace accounting approach. Through his evaluation of the services trees provide, McPherson found that market prices tend to

[158] **McPherson, E. Gregory.** 1992. Accounting for Benefits and Costs of Urban Greenspace. *Landscaping and Urban Planning*. 22:41-51.

undervalue trees and landscaping due to the generally "free" nature of services such as stormwater retention and air pollution mitigation. He also found that the presence of trees such as mesquites was so valuable in Tucson, Arizona, that one person living there would be able to offset his personal carbon emissions by the planting of 12 trees. Each mesquite tree was found to annually intercept 35 pounds of dust and 73 gallons of stormwater runoff, providing a total net benefit to the city of nearly $8.40 each year. In addition, each tree provided shade worth nearly $4.50 each year, and lowered temperature to the tune of nearly $16.50 annually. The total savings for each tree amounted to over $29 per tree each year, with a benefit-cost ratio of 2.6:1.

The findings in this study illustrate the potential importance of street trees to communities, particularly in drier, warmer climates, like those in Southern California. Through this study, McPherson set the groundwork for how the benefits of urban trees could be calculated. His subsequent research has become more sophisticated, including modeling software that could be used by Caltrans and its partner communities.

Dwyer and Miller (1999) conducted a study using GIS to value the benefits of the urban tree canopy to residential areas of Stevens Point, Wisconsin.[159] The researchers used the software program CITYgreen® to examine the land use, land cover, and patterns of summer air-conditioning use in the study area in order to extrapolate the shading benefits from each tree. The land use data was also combined with precipitation and hydrologic soil group information to analyze the stormwater runoff capacity of the area. The software calculated a savings of $126,859 due to lowered air-conditioning costs via tree shading. The stormwater runoff analysis found that the hypothetical storm would produce 2 billion liters (528 million gallons) of stormwater, of which 20%, or 400 million liters (105.6 million gallons), would runoff into a nearby river. Not surprisingly, the areas with the highest amount of tree canopy experienced the least amount of runoff. The model was also able to recommend priority open space areas after the energy savings and runoff analysis, and provides the possibility of suggesting preservation areas for other communities.

[159] **Dwyer, Mark C.** and Robert W. Miller. 1999. Using GIS to Assess Urban Tree Canopy Benefits and Surrounding Greenspace Distributions. *Journal of Arboriculture* 25 (2):102-107.

Although this study did not examine commercial areas, the findings should be transferable, and may in fact be more important in those areas due to the large amount of impervious surfaces such buildings, roadways, and parking lots. Many places in California have struggled with water shortages in 2008, so techniques such as tree-planting and selective landscaping could prove invaluable with regard to reducing stormwater runoff. In addition, the benefits gained by shading that trees should be planted in places where pedestrian traffic is likely, such as along arterial roadways and main street highways.

Xiao and McPherson (2002) studied rainfall interception by street trees and park trees in Santa Monica, California.[160] Using a single-tree rainfall interception model, rainfall interception was determined for various tree types at different stages of growth. The results were interpolated for the city's entire inventory of 29,299, 87% of which were street trees. The researchers found that interception rate varied by tree species and by tree size. The key general finding was that broadleaf evergreens provided the most annual rainfall interception, generally a full 60% of the rain falling on the tree. The next best performing tree type was conifers, which intercepted 23%. In terms of specific tree types, rainfall interception ranged from 15.3% (0.8 m^3/tree) for a small *Jacaranda mimosifolia* (3.5 cm diameter at breast height (dbh)) to 66.5% (20.8 m^3/tree) for a mature *Tristania conferta* (38.1 cm dbh). The researchers also found that rainfall interception varied seasonally, averaging 14.8% during a 21.7 mm winter storm and 79.5% during a 20.3 mm summer storm for a large, deciduous *Platanus acerifolia* tree.

In the city as a whole, the trees intercepted 1.6% of total annual precipitation. The researchers calculated that annual value of avoided stormwater treatment and flood control costs associated with reduced runoff was $110,890 ($3.60/tree).

Air Quality Improvements

Another study by **McPherson et al. (1999)** looked specifically at the urban forest in Modesto, California, in order to ascertain whether or not the benefits accrued by maintaining the forest

[160] **Xiao, Qingfu and Gregory E. McPherson.** 2002. Rainfall Interception by Santa Monica's Municipal Urban Forest. *Urban Ecosystems* 6: 291-302.

justified the annual $2+ million budget.[161] The researchers used the city's street tree inventory database (75,649 trees; 184 species), and sampled 648 trees belonging to the 22 most prevalent species. The sample was stratified into 2 groups: young and old (more than 29 years). Through fieldwork, they measured: diameter at breast height (dbh), tree and bole height, crown radius, tree condition, and severity of pruning; crown volume and leaf area were estimated via computer processing of digital images. Nonlinear regression was used to create a best-fit predictive model of dbh as a function of age for each species, and nonlinear models were used to create predictions for leaf area, crown height, and tree height as a function of dbh.

To determine costs, the researchers used 1997-98 figures from the Community Forestry Division of Modesto. Benefit values were determined based on previous technical reports from McPherson and others, but also estimated using implied valuation methods. To develop the final value, the researchers compared the net annual energy savings, annual air quality improvement, CO_2 reduction, annual stormwater runoff reduction, and aesthetics and other benefits, with the costs to establish and care for the trees, as well as administrative and other costs of the tree program. The result was a total benefit to Modesto residents of $5 million, or an average of $54/person per street tree and $57/person per park tree.

The data revealed that park trees had a greater impact due to their typically larger crown and leaf area, but the benefits also differed depending on the type of tree. Because 83% of the trees in the study were street trees, it can be assumed that the streets trees had the same annual benefits as the average tree. In addition, the greater volume of street trees indicates that the vast majority of the savings – approximately $4 million – is attributable to the street trees rather than to the park trees. Rapid-growth trees often provided high annual benefits, but long-lived trees tended to produce the greatest overall benefits. Table 22 illustrates a breakdown of the benefits per tree.

[161] **McPherson, E. Gregory**, James R. Simpson, Paula J. Peper, and Qingfu Xiao. 1999. Benefit-Cost Analysis of Modesto's Municipal Urban Forest. *Journal of Arboriculture* 25(5): 235-248.

Table 22. Net Benefits of Trees in Modesto, California

Benefit Category	Total $	% of Total Benefit	Avg $/Tree
Energy	1,000,560	20.2	10.64
CO2	449,445	9.1	4.93
Air Quality	1,442,036	29.1	15.82
Stormwater	616,139	12.4	6.76
Aesthetic & Other*	1,455,636	29.3	15.96
Total Benefits	4,963,816	100	54.40

*Aesthetic & Other is composed of visual aesthetic value as well as influence on property values

This analysis did not include the increased ozone formation from biogenic VOC's, nor the benefits from the lowered summer air temperatures and reduced biogenic and anthropogenic hydrocarbon emissions; the consideration of these elements would likely have led to an even greater net benefit. The benefits gained from the aesthetics category were subjective: the researchers used the data from a study of residential sales prices in Athens, Georgia as a proxy. (Past research found a large tree in the front-yard increased the average sale price of a resale house by $508 [1998 dollars].)[162] The study provides a good model for other cities performing cost-benefit analyses on their municipal forests, and demonstrates a clear benefit to cities from these forests, including the presence of street trees.

Maco and McPherson (2003) examined the municipal tree inventory in Davis, California, to understand the benefits and costs to the city.[163] The researchers combined a rapid sampling technique (stratified random sampling) developed in the Modesto study reviewed above with existing data published by the U.S. Forest Service's Center for Urban Forest Research to develop a quick and low-cost approach for analyzing street tree populations in small communities. The resulting model produces four types of information:

- Resource structure (species composition, diversity, age distribution, condition, etc.)
- Resource function (magnitude of environmental and aesthetic benefits)
- Resource value (dollar value of benefits realized)

[162] As quoted in McPherson et al., 1999:
Anderson, L.M., and H.K. Cordell. 1988. Influence of trees on residential property values in Athens, Georgia (U.S.A.): A survey of actual sales prices. Landscape Urban Planning 15 (1988): 153–164.
[163] **Maco, Scott E.** and E. Gregory McPherson. 2003. A Practical Approach to Assessing Structure, Function, and Value of Street Tree Populations in Small Communities. *Journal of Arboriculture* 29(2): 84-97.

- Resource management needs (sustainability, canopy cover, pruning)

The following unit prices for tree benefits and costs specific to Davis were developed:

- Energy Savings were based on a conservative estimate of electricity and natural cost costs using average local baseline.
- Atmospheric CO_2 Reduction was estimated as lower CO_2 emissions due to less electrical generation by PG&E (likely an underestimate of actual costs as PG&E relies on fossil fuel sources as well).
- CO_2 was valued at $0.033/kg, per California Energy Commission recommendations.
- Air Quality Improvements were estimated as the weighted average of all criteria pollution emission reduction credit (ERC) transaction costs for the local region; NO_2 = $8.48/kg, PM_{10} = $9.84/kg, and VOC's =$3.32/kg.
- Stormwater Runoff Reductions were estimated as the total annual city expenditures on stormwater management divided by total annual runoff; $0.499/$m^3$ of stormwater managed.
- Property Values (proxy for Aesthetic and Other Benefits) relied on previous research that found a large front-yard tree was associated with a 0.88% increase in average home resale values. To determine Davis' trees' capacity for increasing home costs, the researcher calculated the average (weighted) leaf surface area (LSA) of a mature large tree in Davis (~400 m^2) and used the average annual change in LSA (m^2) for trees within each dbh class as a resource unit.

The researchers determined a net benefit of $66.41 per tree in Davis, for a citywide total of approximately $1.2 million and a benefit-cost ratio of 3.8 to 1. Not surprisingly, larger trees, both deciduous and coniferous, provided the most benefits. The assumptions in this study regarding street tree growth were taken from the previous Modesto study, and therefore may not completely reflect the situation in Davis. However, the researchers did test the data to make sure the assumptions would be close enough to be reliable. As with any study involving the quantification of costs and benefits not generally quantified, such as CO_2 reduction, there are difficulties in measuring the full impacts. However, this type of analysis will only become more important, as California moves toward goals of greenhouse gas reduction. In that regard, street

trees along Caltrans roadways, particularly heavily traveled roadways in urban areas such as arterials, will also likely become increasingly important. This study is a great example of the type of thorough analysis that will likely be necessary in the future.

McPherson et al. (2005) looked at tree populations and maintenance costs in Fort Collins, Colorado; Cheyenne, Wyoming; Bismarck, North Dakota; Berkeley, California; and Glendale, Arizona to compare the cost/benefit ratios in each place.[164] The five cities were selected from sites where the U.S. Forest Service had conducted extensive sampling of public trees, developed growth curves, and used the Street Tree Resource Analysis Tool for Urban Forest Managers (STRATUM), a numerical modeling program, to estimate annual municipal forest benefits and costs. In each city, 30–70 trees from the city's most abundant species were randomly selected for study. For each tree, the researchers measured diameter at breast height (dbh), tree and bole height, crown radius, tree condition and location, adjacent land use, and severity of pruning. Leaf area (LA) and crown volume were estimated from digital images. The researchers created a model to predict dbh as a function of the age of each tree species, and tree LA, canopy diameter, and tree height were then modeled as a function of dbh. In addition, two years of annual tree program expenditures were collected from city agencies.

Three structural measures were used for analysis: 1) "Full street tree stocking" was assumed to be one tree every 50 feet; 2) "Importance values" (IV) were calculated to determine the relative dominance of tree species in each city; 3) "Typical" tree traits were determined by dividing total crown projection area (CPA), LA, and other attributes by the total number of trees. Tree growth rate information was used to model annual growth of each city's urban forest (tree population held constant). Prices were assigned to the environmental benefits provided by the trees via direct estimation and implied value as environmental externalities in the following ways:

- Energy Savings*:* Changes in building energy used cause by tree shade were determined by computer simulation incorporating building, climate, and shading data.
- Atmospheric CO_2 Reductions*:* CO_2 sequestration rates were determined from prior research on tree growth and biomass equations for urban trees.

[164] **McPherson, Greg**, James R. Simpson, Paula J. Peper, Scott E. Maco, and Qingfu 8. 2005. Municipal Forest Benefits and Costs in Five US Cities. *Journal of Forestry* (December):411-416.

- Air Quality Benefits*:* Hourly pollutant dry deposition was calculated as a product of deposition velocity, pollutant concentration, CPA, and time. Air quality benefits also included reduced emissions from reduced energy use; biogenic VOC's were considered, as well.
- Stormwater Runoff Reduction*:* A numerical interception model was used to calculate the amount of annual rainfall intercepted by the trees. The water volume a tree could store in its crown was calculated based on CPA, LA, and possible water depth on canopy surfaces. The model incorporated local rainfall data.
- Aesthetics and Other Benefits*:* These benefits were only somewhat captured in the research. The proxy used was based on research that had determined the difference in sales prices of residential properties with trees to be 0.88% greater than those without.

After examining the data, the researchers concluded that the trees produced a net benefit in every environment. However, just as there was a range of money each community spent on trees, there was also a range of benefits derived from the trees: the overall net benefits ranged from $1.37 - $3.09 per dollar spent, which translated into a low of $31/tree in Glendale and a high of $89/tree in Berkeley. Although the benefits such as stormwater runoff and energy reduction were subject to local climates and costs for treatment, the research revealed that the largest benefits came from the "aesthetic and other" category in all cities except Bismarck.

While the research was impressive for its sophisticated measures of tree characteristics and its inclusion of so many environmental factors into the model, it could have been strengthened by including the effects of shading on pavement and the resultant reduction in the urban heat island effect. Two questions remain:

1) Does the model really include all environmental costs?
2) Are the values that the researchers assigned to the various costs and benefits accurate? This is particularly important with regard to aesthetic values.

Overall, the research clearly demonstrates that the amount of benefits contributed by a city's urban forest depends to a large extent on the structural qualities of a city's trees and where they are planted. The most beneficial trees are shade trees that have long lives and broad canopies,

intercept a high amount of radiation and rainwater, and emit low levels of VOC's. For energy savings, it is important that trees are planted where they will shade buildings. In addition, the research shows that the large number of local variables that must be measured to determine the benefits and costs of a city's urban forest make it impossible to generalize the benefits and costs across California cities. However, the use of STRATUM demonstrated a method usable by Caltrans and its partner communities to more easily conduct local analysis of street tree benefits.

Thompson et al. (2004) conducted an analysis of a tree-planting program in Iowa communities to better understand the impacts of the newly planted trees and savings to the communities.[165] The researchers obtained a random sample of twenty Iowa communities who had participated in the tree-planting effort, ensuring that all parts of the state and communities of all sizes were represented. The researchers then identified 10-20% of the newly planted community trees for testing (932 total) and measured them repeatedly from spring 1997 to spring 2000 in order to gauge height, diameter at breast height (dbh), canopy width, canopy shade, and foliage measurements.

Individual tree measurements of the 847 living trees in spring 2000 were used to calculate average tree height, dbh, and canopy width for the entire population of trees, and by species for the 10 most common species in the population. The average height for all trees was 4 meters (13.1 feet), average dbh was 69 mm (2.7 inches), and average crown width was 2.7 meters (8.9 feet). The Urban Forest Effects (UFORE) model was then used to estimate carbon sequestration and air pollution removal provided by the trees, using 1998 field data and 2000 hourly pollution and weather data as the base. Estimates based on prior street tree growth rates were used to approximate annual carbon sequestration.

The UFORE model calculated 2,252 kg (~4,965 lb.) of carbon stored by the trees, about 2.7 kg/tree (6 lb./tree). Annually, the total carbon sequestration amounted to about 568 kg/yr (1252 lb./yr), or about 0.68 kg/tree (1.5 lb./tree). The trees as a group removed a total of 21.2 kg/yr (47 lb./yr) of air pollution, approximately $117.30 in value. The greatest removal was for ozone

[165] **Thompson, J.R.**, D.J. Nowak, D.E. Crane, and J.A. Hunkins. 2004. Iowa, U.S., Communities Benefit from a Tree-Planting Program: Characteristics of Recently Planted Trees. *Journal of Arboriculture* 30 (1):1-10.

and particulate matter smaller than 10 microns. The researchers noted that if the trees were larger, significantly more carbon would have been sequestered - trees with a width of greater than 75 cm (2.5 feet) dbh will remove 65–67 times more pollution than trees less than 7.5 cm (3 inches) dbh, according to previous studies. If all trees measured in this study grew to that girth, 1399.2 kg (3,085 lb.) of air pollution would have been mitigated, resulting in a savings of $7,741.80 for the communities as a whole. (It is likely that this number would be even greater in 2008 dollars, as air pollution is a creeping, continuous problem for most medium- to large-sized cities.) Specific air pollutant removal measurements follow in Table 23.

Table 23. Total estimated pollution removal (kg/yr) and associated monetary value (dollars/yr) for 879 street trees in Iowa during nonprecipitation periods (dry deposition) in 2000. Monetary value of pollution removal by trees was estimated using the median externality values for the United States for each pollutant (Murray et al. 1994). Externality values for ozone were set to equal the value for NO_2.

Pollutant	Removal (kg/yr)	Value (US$/yr)
Ozone	10.2	68.6
Particulate matter < 10 μ[z]	6.4	28.8
Nitrogen dioxide[y]	2.5	16.7
Sulfur dioxide	1.7	2.8
Carbon monoxide	0.4	0.4
Total	**21.2**	**117.3**

[z] Assumes 50% re-suspension of particles.
[y] Because there was no complete data set on nitrogen dioxide (NO_2) concentrations in Iowa, estimates of NO_2 removal by trees in Iowa were based on removal rates for trees in Omaha, Nebraska in 1994 (0.73 g/m^2 of canopy cover). This estimate is reasonable due to geographical proximity of Omaha to Iowa; also, removal rates in Omaha were relatively low compared to data from other cities in the United States.

Extended Material Life

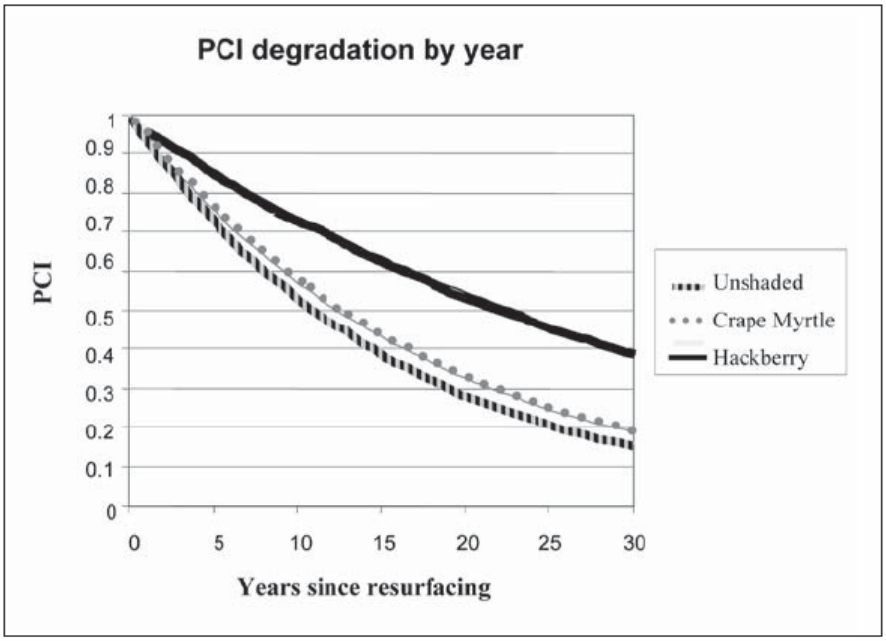
McPherson and Muchnick (2005) examined the effects of street tree shade on asphalt concrete pavement performance in Modesto, California.[166] Using information from the street tree inventory in Modesto, California, GIS data, and street service records, the researchers studied 48 street segments divided into 24 low shade/high shade matching pairs; all segments were 125 feet long and had 35-foot wide asphalt pavements. All streets were controlled for approximate age (built between 1950 and 1960), use (residential), tree history, and maintenance history. All but 4

[166] **McPherson, E. Gregory** and Jules Muchnick. 2005. Effects of Street Pavement Shade on Asphalt Concrete Pavement Performance. *Journal of Arboriculture* 31(6): 303-310.

of the matched pair segments were on the same street, which helped control for traffic volumes; the 4 other segment pairs were from streets nearby each other. Tree data collected during the summer of 2001 was used.

The researchers calculated the Pavement Condition Index (PCI) and Tree Shade Index (TSI) for each street segment. The PCI was calculated based on pavement distress types, amounts, and severities using the Metropolitan Transportation Commission's standard six-step protocol. The TSI was calculated based on tree dimensions and crown density, tree location, foliation period, and segment size, and the use of a Shadow Pattern Simulation (SPS) computer model to calculate the average amount of shade a street segment received as a percentage of maximum possible shade during the March through October foliation period. Three hypothetical scenarios were created to demonstrate how the amount of tree shade influences preventive maintenance expenditures over a 30-year period—an unshaded street segment, and a street shaded by small trees (crape myrtle) with closer spacing, a street shaded by larger trees (hackberry) on wider spacing. Descriptive statistics were used to analyze the relationship between TSI and PCI.

Figure 7. PCI degradation curves for the unshaded street versus shaded street, Crape Myrtle Drive, and Hackberry Drive



Unshaded street (TSI = 0), Crape Myrtle Drive (TSI = 9), and Hackberry Drive (TSI = 41).

The analysis revealed a positive association between better pavement condition and higher amounts of tree shade. An unshaded street segment required 6 slurry seals over 30 years, while a street segment with crepe myrtles (14-foot crown diameter) required just 5 slurry seals over the same time period. However, street segments shaded by Chinese hackberry (45-foot crown diameter) only needed 2.5 slurry seals over the same time period. Shade from the large hackberries was projected to save $7.13/m^2 over the unshaded street segments. This is a savings of 58%, while the crepe myrtle-shaded areas posted a savings of 18%. Figure 6 illustrates the Pavement Condition Index (PCI) for the street segments and resurfacing histories It would be instructive to see research of this same type that examined commercial roads, which tend to carry much higher traffic volumes than residential streets. Regardless, it seems clear that tree shading contributes to longer lifetimes of materials used, and therefore should save money in places where Caltrans is responsible for maintaining the quality of the roads. In addition, this research did not examine the connection between the benefits of street tree shade and reduced urban heat island effect or reduced pollutant evaporation (from fuels leaked by cars, etc.) – both of which could be significant. Future research that more fully deals with those aspects could be enlightening and further demonstrate the benefits of street trees.

Summary of Key Research Findings

The following is a summary of the key findings on the research related to corridor roadside design and environmental effects:

- In general, urban trees have significant impacts on their environs by reducing energy usage, stormwater runoff, and maintenance costs. These trees help improve air quality and increase shading.
- Street trees greatly reduce solar radiation and provide sidewalk shade, which increases pedestrian comfort and physical well-being.
- One study found average annual savings ranging from $5.22 for a small public tree to $46.82 for a large public tree. A small private tree saved $11.73, while a large private tree saved $51.46.
- Over a 40-year period, a group of 100 trees (20 small, 30 medium, and 50 large) were projected to save $143,084.

- A combination of tree planting and high-albedo surfaces could lead to an air temperature reduction of up to 6 degrees in hot urban areas.
- Pavements shaded by street trees can be up to 20 degrees cooler compared to unshaded pavements, influencing local air temperature and mitigating the urban heat island effect.
- Paved areas with 50% tree coverage saw a 5% reduction in emissions versus unshaded areas.
- Urban trees contributed to energy savings of approximately $20 million through shading and reduction of wind speed and temperature.
- Planting 50 million trees to shade east and west walls of buildings would save about $3.6 billion in energy usage after 15 years. It would also offset 60% of the increased electricity consumption associated with California's projected 8 million new residents.
- In dry climes, urban trees can save nearly $30/year in interception of dust and stormwater runoff, as well as by providing shade.
- A cost savings of nearly $127,000 was attributed to tree shading, and a strong association was found between the amount of stormwater retention and the amount of tree canopy in an area.
- An average benefit of $54/person per street tree ($5 million overall) was found in Modesto, California.
- A net benefit of over $66 per tree was found for Davis, California, for a citywide total of approximately $1.2 million. The benefit-cost ratio was 3.8:1.
- Pavement shaded by street trees required as little as one-third the maintenance sealants of unshaded pavement.

Future Research Needs

The ecological contributions of urban trees and greenery have been well-researched. However, it is likely that new research will be needed in order to understand the evolving environmental impacts of climate change. This will be particularly important in urban areas, which may struggle with the provision of water, disproportionate amounts of air pollution, and possible adverse health effects of rising temperatures. Another area for future research will be finding drought tolerant plants and trees that can provide the environmental benefits chronicled here, but

that are able to survive the drought-like conditions that much of the Southwest and Southeast United States experienced in 2008.

- There is a need to better understand the unique ecological contributions of street trees to the urban environment, particularly along arterial streets.
- There is also a need to understand the proportion of street trees that compose the urban forest studied in many research pieces, in order to better understand how to generalize the findings.
- Research also needs to be conducted to better understand the point of emission relationship between trees and vehicles; do trees directly on roadways work harder than trees in parks?
- With regard to stormwater runoff, research should be conducted to see if street trees could be used to justify a reduction in stormwater infrastructure.

CHAPTER VI: CONCLUSION AND NEXT STEPS

Synthesizing the Research Findings

The research reviewed in this report examined multiple features of transportation corridors, and how those features affect traffic safety for drivers, pedestrians and bicyclists, walkability and physical activity, emotional health of passers-by, residents, and visitors, the local environment, and the economic vitality of the community. The findings generally indicate a need to rethink the way highways are currently designed – an effort that dovetails well with Caltrans' policy on Context Sensitive Solutions. Several themes emerge from the literature:

Driver Safety

The range of findings concerning the association between driver safety and corridor design elements indicates that this is an area still very much in flux. *Roadside landscaping was generally found to improve highway safety, but the literature is unsettled about the danger versus benefits that roadside trees pose to those driving along the roadway, and researchers debate how to interpret crash statistics*. Many of the comparative crash rate studies that found roadside trees to be associated with higher numbers of crashes did not analyze vehicle speed data, while the studies that did incorporate speed data generally found that many collisions involving trees also involved speeding, calling into question the "fault" of the tree. Aggregated, these findings suggest that *current highway design guidelines may be missing key opportunities to improve traffic safety, and underscore the importance of highway design to communicate appropriate speed*, as posted speed limit signs appear to be limited in efficacy.

Pedestrian Safety

The cumulative research on pedestrian safety is more straightforward, although there is some ambiguity about how well site-specific case study findings can be generalized to the range of Caltrans highway types and community contexts. In general, traffic calming was found to be an effective way to increase pedestrian safety, but the efficacy of the treatments depends largely on the urban context and amount of pedestrian activity and automobile traffic. Although many studies conclude that speed humps are the most reliable method of slowing traffic, other measures, such as center medians, traffic circles, and roadway narrowing appear to be be

effective in certain circumstances. *The research was clear that there is no one-size-fits-all traffic calming treatment, but that a combination of pedestrian safety enhancements, when thoughtfully implemented, holds promise for improving pedestrian safety*.

The research on crosswalk design and pedestrian safety is more conclusive. Several pieces documented that pedestrians often have a false sense of security at marked but unsignalized crosswalks, leading them to be less cautious of passing traffic than they perhaps should be. Other pieces documented that many drivers often ignore pedestrian right-of-way rules and fail to stop for pedestrians waiting at crossings. The general conclusion, therefore, was that *at unsignalized* crossings, *crosswalk markings should be installed along with ancillary traffic calming techniques, such as flashing in-pavement lights, red or flashing beacons, a speed table, or bulb-outs, to give the driver extra alerts and to enhance pedestrian visibility*.

Physical Activity and Walkability

Another theme, as expressed in the literature on walkability and its connection to physical health, is that *walkability is influenced by the connectivity of streets, provision of sidewalks, and design of the neighborhoods and roadways* as well as by a mix of land uses. The literature also suggested that *those who live in walkable nieghborhoods walk more than those who do not,* even controlling for self-selection, and that *they are generally less likely to be overweight or obese*. Related literature suggested that *people are willing to walk farther than commonly assumed (one-half mile versus one-quarter mile) for utilitarian purposes*, and that walking for all purposes is enhanced by wayfinding measures. In addition, research approaches that incorporate the idea of pedestrian LOS seem to be a promising way to inform transportation design, although the best ways to define and measure it are still being studied.

Bikability

Little research has been done on either the factors that influence the propensity to bicycle or the effects of highway design elements on bicycle safety. However, research completed to date indicates that *well marked on-street bicycle lanes tend to be preferred by the majority of bicyclists, and may even encourage more people to cycle*. Future research incorporating bicycle LOS measures that have recently been developed will likely shed light on this underdeveloped

subject. In addition, cities such as Portland, Oregon, and Manhattan, New York, continue to innovate in this area, illuminating studies will likely be released in the next couple of years.

Psychological Well-being

The various research studies looking at the benefits of nature on the psyche found that *time spent viewing greenspace or being outside in a calm environment enhanced positive feelings both directly and indirectly by taming stress and frustration, and was associated with improved performance on subject tests*. In particular, *the presence of roadside landscaping has been tied to reduced traffic stress for both drivers and those who live along heavily traveled corridors*. Other research indicated that *humans generally prefer to live near greenery and mature trees,* and that *greenery and mature trees near apartments was associated with greater community interaction*. In sum, this research suggests that incorporating landscaping along roadways will enhance the psychological health of those who drive, work, and live along these roadways.

Community Economic Vitality

There is not much literature on the relationships between corridor design elements and community economic vitality, as this subject matter has not been studied to the same extent that traffic safety or the connection between nature and improved health has been. However, the research that has been done indicates that *for both commercial and residential areas, the presence of landscaping and trees generally improves property or rent values and attracts people*.

Environmental Effects

The theme throughout the environmental literature was that *trees in urban areas tend to be overwhelmingly beneficial for communities*. In particular, *urban trees help reduce energy consumption, mitigate urban heat island effects, retain stormwater, and mitigate air pollution.* Some research studies found that *urban street trees that shade both buildings and paved surfaces make important contributions to energy savings, emission reduction, and heat island mitigation*. In addition, *the shade from trees prolongs material life*, such as roadway slurry seals, which may be a benefit of particular interest to Caltrans. Other research studies found that *trees are more efficient at mitigating the urban heat island effect when greenspace is below their canopy,*

suggesting that street trees should be planted over grass or other plant material where possible; this should simultaneously aid in stormwater capture and retention. The literature strongly suggests that careful street tree selection is important, as *the greatest tree benefits come from those species that are deciduous, fast-growing, tall, broad- canopied, and low VOC emitters.*

Implications for Caltrans

When looked at holistically, the cumulative literature seems to recommend some key guidelines for Caltrans highway design:

<u>Conventional Highways (urban & suburban arterials, "main streets," and rural highways)</u>

1. Ensure that traffic calming measures, sidewalks, and crosswalks are installed in a systematic and correlated manner so that pedestrians will have the best chance of walking safely along any Caltrans right of way; speed calming techniques will also likely contribute to driver safety.
2. Ensure that bicycle facilities in the form of bicycles lanes, bicycle boulevards, shoulders, and supplementary treatments such as sharrows, are systematically provided and connected to provide a system wherein bicyclists feel comfortable and can interact safely with traffic. The more bicyclists there are on the road, the safer each bicyclist will be.
3. For arterial or other highways where residential and commercial uses attract people, roadside green space, particularly trees, should be provided as much as is reasonable and safe. Such green space will enhance the area by responding to what seems to be a primal reaction of calm and pleasure in the face of semi-tamed nature. In residential areas, this could lead to greater resident satisfaction and safety; in commercial areas, this could lead to greater sales revenue, as shoppers seek out places they feel comfortable.
4. Both the landscaping and the pedestrian treatments will make it more likely that people will walk for either utilitarian or recreational purposes, thus contributing to their overall health and potentially reducing the amount of car usage in the area.
5. Providing roadside landscaping, especially trees, will also lessen the local environmental damage caused by air pollution, stormwater runoff, and energy consumption.

Limited-Access Highways

1. Providing greenspace along the highway may help to maintain driver attention and reduce driver fatigue, leading to a safer roadway.
2. The design of the roadway is imperative to communicating the desired speed. Depending on the type of highway, center medians, narrow lane widths, narrow shoulders, and roadside landscaping should be considered as design elements to encourage the desired speed.
3. Roadside trees should not be banned outright. Rather, their inclusion in a highway design should be thoughtfully considered in light of the research that indicates well-located trees can have safety benefits.
4. Providing roadside landscaping, especially trees, will lessen the local environmental damage caused by air pollution, stormwater runoff, and energy consumption.

Next Steps

The second phase of this study, the development of performance measures, has commenced with the completion of this literature review. This literature review provided the foundation for the on-going research project, and will be used, in conjunction with additional research, to develop the performance measures, which are intended to help guide Caltrans project planning in the future.

The end goal of the project is to produce a document that will guide Caltrans about strategies to design roadways in a more holistic manner, in keeping with Caltrans' goals for Context Sensitive Solutions. The associated performance measures will enable the process to be shared with other transportation agencies, with the aim of contributing to the movement towards multimodal systems throughout the transportation planning and engineering professions.

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APPENDIX I: APPROPRIATE TRAFFIC CALMING PER ROADWAY TYPE[167]

Technique	Appropriate on Local Residential Streets	Appropriate on Collectors and Arterials
ROADWAY DESIGN TECHNIQUES		
Chicanes	√	
Neckdowns/chokers	√	√
Central Narrowing Islands	√	√
Roadway Narrowing Techniques	√	
Full Closures	√	
Half Closures	√	
Entrance Features	√	√
Traffic Circles	√	
Roundabouts		√
ROADWAY DESIGN TECHNIQUES		
Speed Humps	√	
Speed Tables, Raised Intersections, Speed Cushions	√	
Crosswalks, Wider Sidewalk Areas	√	√
Bicycle Mobility Techniques	√	√
Innovative Pavement Markings	√	√
Rumble Strips		√
TRAFFIC CONTROL TECHNIQUES		
Speed Limit Signs and Pavement Markings	√	√
Stop Signs	√	√
Warning Signs	√	√
School Speed Zones	√	√
Flashing Beacons		√
Signal Coordination		√
Unique Traffic Control Sign	√	√
ENFORCEMENT TECHNIQUES		
Citizen Speed Watch Programs	√	√
Increased Enforcement (Conventional)	√	√
Speed Trailers	√	√
Automated Enforcement	√	√

[167] Parham, Angelia H. and Kay Fitzpatrick. 1999. Investigating Speed Management Techniques. Texas Transportation Institute.

APPENDIX II: SUMMARY OF KEY FINDINGS OF THE STUDIES INCLUDED IN THIS REVIEW

ARTERIALS

Reference	Year	Title	Findings / Summary
Abdelghany	2005	Above-Ground Actuated Yellow Crosswalk Lights at Uncontrolled Pedestrian Crossings	Pavement-embedded flashing lights were found to be more successful at reducing vehicle speeds and encouraging pedestrian crosswalk compliance than above-ground flashing lights, which were only slightly successful. Both types of flashing lights were successful at reducing pedestrian/vehicle conflicts at mid-block locations (66% reduction).
Alta Planning + Design	2004	San Francisco's Shared Lane Pavement Marking: Improving Bicycle Safety	Observational data showed that when sharrow markings were present, cyclists tended to ride about 8 inches further from parked cars. The markings also influenced the cyclists to ride further from parked cars when being passed by motor vehicles, although the distance decreased to 3-4 inches. Even cars tended to drive about 1 foot further away from parked cars due to the sharrow marking. The markings were also positively associated with reductions in the number of sidewalk riders, as well as wrong-way riders.
Baltes and Chu	2002	Pedestrian Level of Service for Mid-block Street Crossings	Pedestrians' perceived level of crossing difficulty increased with higher total volumes of traffic, higher numbers of turning movements, higher average speed, and greater crossing width of streets. Perceived level of service (LOS) increased as the width of painted or raised medians increased, and the presence of a crosswalk increased LOS. Pedestrian signals and cycle length were also significant, although more research needs to be done to determine affects on LOS.
Boarnet et al.	2005	Evaluation of the California Safe Routes to School Legislation - Urban Form Changes and Children's Active Transportation to School	Three times as many children who lived on the SR2S route walked or biked post-improvement as those who did not live along the route, particularly if the SR2S project included sidewalk improvements or traffic control projects.

Cooper et al.	2003	Commuting to School - Are Children Who Walk More Physically Active?	Children who walked to school were found to be significantly more active during the hour from 8–9 a.m. than those who were driven. Active travelers were also found to have significantly more moderate-to-vigorous physical activity. Boys, in particular, were involved in significantly more physical activity from 3–8 p.m. if they walked to school.
Cross and Mehegan	1988	Young Children's Conception of Speed: Possible Implications for Pedestrian Safety	Children under age 9 do not understand the relationship between distance and speed, and cannot be expected to behave in a manner adults consider "rational". This reality should influence both street design and the design of traffic education for children.
Dill and Carr	2003	Bicycle Commuting and Facilities in Major U.S. Cities	The number of Class II bicycle lanes/sq. mi. explained the largest share of bicycle commuting rates. For U.S. cities with populations greater 250,000, each additional mile of Class II bicycle lanes/sq. mi. is associated with approximately 1% increase in bicycle commuters.
Dill and Voros	2007	Factors Affecting Bicycling Demand - Initial Survey Findings from the Portland, Oregon, Region	Current cycling patterns were significantly positively associated with how often people rode their bicycles for fun or to places other than school as a child. In addition, the researchers found a positive association between regular cycling and observing other adults cycling on one's street at least once per week. Utilitarian cycling was positively associated with living in neighborhoods with higher street connectivity, particularly streets leading to desirable destinations (such as Portland's bicycle boulevards). The findings regarding bicycle lanes were mixed (positive or no effect), which the researchers believe may be due to the study design. Barriers to cycling that were related to roadside design were cited as: too much traffic; lack of bike lanes or trails; and lack of safe places to bike.
Dixon and Wolf	2007	Benefits and Risks of Urban Roadside Landscape: Finding a Livable, Balanced Response	A review of numerous locally and regionally oriented research studies revealed no indication that roadside trees proved a significant or constant traffic safety risk.

Dulaski	2006	An Evaluation of Traffic Calming Measures and Their Impact on Vehicular Speeds on an Urban Principal Arterial Roadway on the Periphery of an Activity Center	A combination of narrowed travel lanes (12 to 11 feet), pedestrian refuge islands, textured crosswalks with pedestrian-activated, in-roadway warning lighting, 4-foot bike lanes, and advanced yield signage led to reduced vehicle approach speeds to crossings. In addition, pedestrian crosswalk compliance increased from just over 54% to over 96% post-installation.
Dumbaugh	2005	Safe Streets, Livable Streets	Compared "livable street" treatments with conventional street design; found that the livable streets were safer in every respect, contrary to current engineering practice.
Dumbaugh	2006	Design of Safe Urban Roadsides: An Empirical Analysis	Livable-street treatments were compared with widened paved shoulders and widened fixed-object offsets as strategies for enhancing traffic safety. Four years of data comparing related street sections showed that only the livable-streets treatment was consistently associated with reductions in both roadside and mid-block crashes - 67% fewer roadside crashes overall than the comparison sections. In addition, over 65% of the urban fixed object collisions in the study resulted from failing to turn properly, rather than from errantly leaving the roadway (contrary to current engineering thought).
Eccles et al.	2004	Evaluation of Pedestrian Countdown Signals in Montgomery County, Maryland	The installation of pedestrian countdown signals at several urban arterial locations was found to encourage pedestrians crossing during the "walk" phase of the signal, and decrease the number of pedestrians in the crosswalk as the light changed to red. In addition, no effect, positive or negative, was observed on driver behavior.
Fitzpatrick et al.	2000	Design Factors That Affect Driver Speed on Suburban Streets.	Controlling for speed limit, lane width was found to be the most significant influence on driver speed for straight roadway sections; for curved sections, deflection angle and access density were the two most significant factors influencing speed, after controlling for posted speed limit.

Fitzpatrick et al.	2006	Improving Pedestrian Safety at Unsignalized Crossings	Motorist compliance for yielding varied according to crosswalk treatment, as well as with respect to the number of travel lanes and posted speed limit. The most effective treatments overall were found to be treatments that included a red signal or beacon, even on high-speed, high-volume arterial streets.
Frank et al.	2007	Stepping towards causation: Do built environments or neighborhood and travel preferences explain physical activity, driving, and obesity?	The prevalence of obesity was lowest in the most walkable neighborhoods, and residents who lived in those neighborhoods were more likely to walk for non-discretionary purposes. Respondents in the least walkable neighborhoods drove significantly more than those in the most walkable environments. Although self-selection was present to a degree, even those who preferred more suburban environments walked more when living in a walkable neighborhood.
Garrard et al.	2008	Promoting transportation for cycling for women: The role of bicycle infrastructure	Observational data of female cyclists' route choices in Melbourne, Australia, revealed a preference for off-road paths over roads without bicycle facilities and roads with bicycle lanes. Neither male nor female cyclists seemed to have a preference between roads with bicycle lanes and roads without them, although the researchers did account for roadway conditions or ADT, which could explain the order of preferences observed.
Godfrey and Mazzella	2000	Success in Redesigning Main Streets for Pedestrians	The installation of pedestrian-activated, in-roadway warning lights on urban arterials in Washington was associated with major improvements in driver yielding behavior - from 16% to 100% in one location. In addition, drivers began to slow further back from every location when the lights were activated. Field observations indicated that pedestrians did not exhibit a false sense of security due to the lights.

Gorman	2004	Residents' Opinions on the Value of Street Trees Depending on Tree Location	Over 91% of respondents classified street trees as being of great benefit, and nearly 62% indicated that they would be willing to volunteer to help maintain the neighborhood trees. Tree qualities identified as significantly positive included shad, aesthetic qualities, flowers, and contribution to increased neighborhood livability and property values. Significantly negative features were identified as the tendency for branches to break during storms, roots to uproot sidewalks, and trees to block visibility.
Gutierrez et al.	2007	Pedestrian and Bicyclist Safety Effects of the California Safe Routes to School Program	Safe Routes 2 School projects were associated with an increase in safety for schoolchildren, albeit against a backdrop of declining rates of walking and bicycling to school nationwide. The program offers promise to begin reversing this trend, although more research is necessary to draw strong conclusions.
Hakkert et al.	2002	An evaluation of crosswalk warning systems: effects on pedestrian and vehicle behaviour	The installation of in-pavement flashing lights at crosswalks was found to reduce the tendency for pedestrians to cross outside of the crosswalk from 50% to 10%. In addition, the rate of vehicle and pedestrian conflicts was reduced to less than 1% for all four sites examined.
Hamilton-Baillie	2004	Urban design: Why don't we do it in the road? Modifying traffic behavior through legible urban design	As a car increases in speed, the risk of injury or death to a pedestrian, if hit, increases dramatically and non-linearly.
Handy	2005	Critical Assessment of the Literature on the Relationships Among Transportation, Land Use, and Physical Activity	Walking and bicycling were consistently found to be correlated with the presence of sidewalks and a gridded street network.

Heisler	1974	Trees and Human Comfort in Urban Areas	Shade trees were found to considerably contribute to the cooling of humans outside. In addition, they work to block solar radiation and long-wave radiation from nearby buildings. In contrast, parking lots store the solar radiation and then re-radiate it, heating the air above the surface and warming the local temperature.
Huang et al.	2000	Effects of Innovative Pedestrian Signs at Unsignalized Locations	The installation of pedestrian signs at several locations around the United States was associated with an increase in pedestrian confidence (less running or hesitation), as well as driver yielding. However, arterials with several lanes did not see an improvement from the installation, suggesting that multiple treatments are necessary to affect pedestrian and driver behavior in such circumstances.
Huang and Cynecki	2001	The Effects of Traffic Calming Measures on Pedestrian and Motorist Behavior	An examination of various crossing treatments found that, in general, more drivers yielded to pedestrians and slowed their approach speeds where multiple crosswalk treatments were implemented, such as a raised crosswalk and an overhead flasher. Some of the improved crosswalks experienced an increase in the number of pedestrians crossing, particularly if a median refuge had been installed.
Hunter and Stewart	1999	An Evaluation of Bike Lanes Adjacent to Motor Vehicle Parking	There were few observed conflicts between vehicles attempting to park and bicyclists riding in an adjacent bicycle lane at the two sites observed. In one case, this was likely due to the low amount of parking turnover; in the other, there were more conflicts with turning vehicles, but they were avoided due to bicyclists adjusting their behavior. Video showed that bicyclists tended to ride further away from traffic when given the space to do so, even though this meant riding closer to the parked cars. The researchers suggest that this was possible due to the low parking turnover and therefore low risk of being doored.

Jacobsen	2003	Safety in numbers: more walkers and bicyclists, safer walking and bicycling	The total number of walkers and cyclists hit by motor vehicles varies with a 0.4 power of the amount of total walking or cycling, strongly suggesting that greater numbers of pedestrians or bicyclists lead to fewer collisions with vehicles. This is attributed to increased driver awareness and caution.
Johnson et al.	2005	Pedestrian and Bicycle Safety Evaluation for the City of Emeryville at Four Intersections	Vehicle turns at red and green lights, as well as unsignalized crossings, were identified as problematic for pedestrians attempting to cross the street. In addition, of the ten crosswalks examined, only four provided enough time for a pedestrian to cross at 4 ft./sec, and only two provided enough time to cross at 2.5 ft./sec. The researchers suggested extended crossing times, leading pedestrian intervals, traffic calming measures, and crosswalk treatments to help mitigate these problems.
King	2000	Calming New York Intersections	Leading pedestrian intervals installed at several New York City locations were found to lead to an average 12% reduction in pedestrian/vehicle crashes and a 55% reduction in crash severity, when compared to control sites.
Knoblauch et al.	2001	Pedestrian Crosswalk Case Studies: Sacramento, California; Richmond, Virginia; Buffalo, New York; Stillwater, Minnesota	The installation of a simple marked crosswalk at several intersections in multiple test cities was associated with slightly reduced approach speeds of vehicles, although the percentage of drivers who yielded to pedestrians did not change. However, most of the crosswalks experienced an increase in the number of people crossing at that location.
Kuo	2003	The Role of Arboriculture in a Healthy Social Ecology	Residents living near green space reported feeling safer and experiencing less disruption than those without green space. Residents were also more sensitive to trees than grass, and tended to spend more time socializing outside if trees were nearby.

Laverne and Winston-Geideman	2003	The Influence of Trees and Landscaping on Rental Rates at Office Buildings	Landscaping with high aesthetic value added approximately 7% to average rental rates. In addition, building shade over 25% provided by landscaping added another 7% to rental rates. In areas where landscaping screened the businesses too much, rental rates decreased by 7%.
Lee and Moudon	2006	Correlates of Walking for Transportation or Recreation Purposes	Walking for transportation was more affected by physical environmental variables such as the average block size, number of street trees, and distance to amenities, than was recreational walking. In contrast, the presence of sidewalks was correlated only with recreational walking. In addition, these variables tended to be more correlated with frequent walking than with moderate walking, suggesting that a "supportive physical environment" may be key in promoting walking. In addition, people who walked for any reason at all were more likely to reach the recommended level of physical activity than those who did not.
Lee and Moudon	2008	Neighborhood design and physical activity	High traffic volume was the most frequently cited barrier to physical activity, followed by too much distance between desirable locations. The presence of street trees, benches, and street lighting was positively associated with facilitating walking in a neighborhood. The presence of bicycle lanes and paths, street lighting, and bicycle racks at destinations was positively associated with facilitating bicycling in a neighborhood. The more active respondents tended to live in areas with fewer vehicle lanes, slower posted speeds, and smaller street blocks. A significant positive association was observed between levels of vigorous physical activity and smaller street blocks.
Litman	1999	Traffic Calming Benefits, Cost and Equity Impacts	Meta-analysis of traffic calming studies; found that 85% of pedestrian fatalities occur on non-local streets such as arterials, and that speed is the main culprit. For example, a pedestrian hit by an automobile traveling 20 mph has a 95% chance of survival; a pedestrian hit at 40 mph has only a 20% chance of survival. The report suggested that thorough traffic calming could lead to increased traffic safety.

Macdonald	2006	Street Trees and Intersection Safety	Results from a computer simulation tested by participant "drivers" indicated that trees, if spaced at least 25 feet apart and pruned no lower than 14 feet from the ground, do not block driving views at an intersection, contrary to popular engineering practice. In contrast, cars parked on the street, as well as newspaper stands located at intersections, appeared to create visibility problems for the test subjects.
Maco and McPherson	2003	A Practical Approach to Assessing Structure, function, and Value of Street Tree Populations in Small Communities	The urban forest in Davis was credited with $1.2 million ($66.41/tree) in reduced energy costs, intercepted runoff and air pollution, and contribution to property values. The overall benefit: cost ratio was 3.8:1.
McDonald	2007	Active Transportation to School - Trends Among U.S. Schoolchildren	Walking to school was found to be much more common than bicycling to school, although both modes have declined since 1969. Average round-trip time for an active trip to school was found to be 20-25 minutes by foot or 17-26 minutes by bike, both of which could add substantially to the daily physical activity quotient for a child. Although greater distance from school was identified as a major reason for the decline in active transport, traffic safety and stranger danger concerns were also cited.
McPherson and Muchnick	2005	Effects of Street Tree Shade on Asphalt Concrete Pavement Performance	Street segments shaded by a medium-sized tree (14-foot crown) needed 5 slurry seals as compared to 6 seals for unshaded segments. Segments shaded by a large tree (45-foot crown) needed only 2.5 seals over the same time period. The large tree was associated with a 58% savings, while the medium tree was associated with an 18% savings.
Mok et al.	2003	Comparison of Safety Performance of Urban Streets Before and After Landscape Improvements	Examination of pre- and post-landscaping collision data revealed a reduction of crash rates by 1-77% at 8 of 10 analysis sites. The two sites where crash rates increased post-landscaping were the only two highway interchanges in the study. Overall tree collisions were reduced by approximately 71% after the improvements; pedestrian fatalities decreased by approximately 47%.

Moudon et al.	2005	Cycling and the Built Environment	Proximity to a bicycle trail and the perception of nearby trails or bicycle lanes were positively associated with cycling. The survey data indicated a strong preference for an increase in the number of bicycle lanes and trails, better lighting along the roadway, and bicycle parking at destinations. Objective analysis suggested that bicycle lanes and traffic volume and speed did not seem to influence bicycling rates, although the researchers attribute this finding to an unexpectedly high level of cyclists in the sample population.
Naderi	2003	Landscape Design in the Clear Zone	Landscaping improvements were positively associated with reduced mid-block collision rates ranging from 5-20%; the improvements lead to an approximate $1 million (Canadian) savings in reduced traffic crash costs. A second study of paths in the "clear zone" of the roadway suggested that the ambience or context of a path greatly influenced a person's perception of the quality of the path. Naderi found that respondents preferred a natural edge if they were walking for health, and that a sense of enclosure, environmental identity, or genius loci was identified as the single environmental variable dividing the "good" from the "not good" sites.
Naderi et al.	2008	The Street Tree Effect and Driver Safety	A driver simulation analysis indicated that suburban streets with trees were perceived by participant drivers as the safest, followed by urban streets with trees; urban streets without trees were perceived as the least safe. The presence of street trees was positively associated with greater sense of spatial edge in both urban and suburban conditions, which contributed to the sense of safety. The perceptions of safety were matched by a significant drop in the cruising speed of most drivers (average drop of 3 mph) when trees were present on the suburban street, regardless of the speed one drove on the suburban street without trees. Urban speed data was found to be confounded by short block lengths.

Nasar	2003	Prompting Drivers to Stop for Crossing Pedestrians	Hand-held signs were found to positively influence the propensity of drivers to yield to pedestrians in a crosswalk, suggesting that social learning about pedestrian awareness may lead to changes in driver behavior that can supplement physical solutions.
Parkin et al.	2007	Models of perceived cycling risk and route acceptability	In a model of perceived cycling risk and route acceptability, cycling along residential roads was associated with increased risk, particularly if there was on-street automobile parking. Parked vehicles along a busy road did not appear to increase perceptions of risk, although the high amount of auto traffic was associated with increased risk. Bicycle lanes were found to mitigate the risk of heavy traffic, but not completely. The presence of a bus lane was also found to somewhat mitigate the perceptions of risk.
Petritsch et al.	2006	Bicycle Level of Service for Arterials	The participating cyclists gave the sections of the course without bicycle lanes or paved shoulders the lowest scores on the route. Females tended to grade sections lower than males, as did participants over 40 in comparison with their younger counterparts. Responses to open-ended questions revealed that the presence or absence of a bicycle lane was the most commonly cited reason for grading a roadway section positively or negatively, respectively. Traffic volumes were the second most cited reason, followed by roadway/pavement condition and space.
Petritsch et al.	2006	Pedestrian Level of Service Model for urban Arterial Facilities with Sidewalks	For arterial roadways with sidewalks, the pedestrian level of service decreases in correlation with the total width of driveway and intersection crossings, as well as the amount of traffic on the adjacent roadway. This finding is applicable for arterials with four or fewer through lanes of traffic.
Petritsch et al.	2004	Level of Service Model for Signalized Intersections for Pedestrians	Right-turn-on-red and permitted left turn conflicts significantly negatively affect pedestrians' perceived level of service, as do the volume and speed of the perpendicular traffic. Pedestrians also seemed to be more affected by the number of traffic lanes they had to cross than the width of the street. The data also indicated that pedestrians were negatively influenced by delay.

Potts et al.	2007	Operational and Safety Effects of Right-Turn Deceleration Lanes on Urban and Suburban Arterials	In general, no significant difference in safety was detected between mid-block lanes 12 feet in width and those less than 12 feet. The exception was undivided 4-lane arterials with lanes of 10 feet or less, and divided 4-lane arterials with lane widths of 9 feet or less.
Ragland and Mitman	2007	Driver/Pedestrian Understanding and Behavior at Marked and Unmarked Crosswalks	Drivers were found to yield at unmarked crosswalks less than marked crosswalks, likely due to ignorance about traffic law. However, fewer collisions occur at these crosswalks, likely due to increased pedestrian care. In contrast, marked crosswalks at intersections with 2+ lanes are associated with greater rates of driver yielding, but also greater risks of multiple threat collisions. Multiple treatments are therefore necessary to enhance pedestrian safety at these crosswalks.
Rajamani et al.	2002	Assessing the impact of urban form measures in nonwork trip mode choice after controlling for demographic and level-of-service effects	The ratio of park area per housing unit was found to positively influence the propensity to walk for recreation. In addition, delay seemed to affect people more when walking or bicycling than when traveling in a covered vehicle, suggesting that pedestrian and bicycle signals and detection devices could encourage walking and bicycling by reducing delay.
Rousseau et al.	2004	The Effects on Safety of In-Roadway Warning Lights at Crosswalks: Novelty or Longevity?	Driver yielding increased significantly after the installation of in-pavement flashing lights; this happened even during a period of malfunction, suggesting that driver learning had occurred. Observational data did not suggest that pedestrians exhibited a false sense of security due to the lights.
Saelens et al.	2003	Neighborhood-Based Differences in Physical Activity: An Environment Scale Evaluation	Residents of the high-walkability neighborhood engaged in approximately 52 more minutes of moderate-intensity physical activity during the week, and were found to have a lower average BMI than the residents in the low-walkability neighborhood. The high-walkability neighborhood was characterized by street connectivity, aesthetics, and safety from traffic.

Saelens and Handy	2008	Built Environment Correlates of Walking: A Review	Increased rates of walking were associated in various studies with increased accessibility to destinations, aesthetic qualities, and sidewalks and network connectivity in general. Traffic safety improvements were also associated with increased walking in some studies.
Schlossberg and Brown	2004	Comparing Transit-Oriented Development Sites by Walkability Indicators	An analysis of transit-oriented developments in Portland, Oregon, revealed that areas with fewer arterial streets were generally considered more walkable than areas with a greater ratio of arterials to minor roadways. The less walkable sites in the study are characterized by the transit node being surrounded by high-volume arterials, which act to isolate it from the rest of the area. The arterials seem to be viewed as barriers to pedestrian activity.
Schlossberg et al.	2007	How Far, By Which Route, and Why? A Spatial Analysis of Pedestrian Preference	The average person in the study walked 0.47 mile to his/her transit stop, suggesting that the standard 1/4-mile planning radius is an underestimate. In addition, time and distance were cited as the two most important reasons to choose a route, suggesting that the provision of direct routes to main thoroughfares or destinations would be appreciated. Safety was also important to pedestrians, including both traffic safety and safety from crime. The presence of sidewalks was cited as a priority for 43% of the respondents, and landscaping/aesthetic factors were a priority for 35% of the respondents. The most important factor in a choice to walk was whether or not the respondent enjoyed the activity, suggesting that investments to make walking more pleasant could result in a greater number of pedestrians. In addition, arterials and collectors received the lowest ratings in terms of walkability, suggesting a need to improve the pedestrian quality of those streets in particular.
Scott et al.	1999	Effects of Tree Cover on Parking Lot Microclimate and Vehicle Emissions	There was a clear connection between the presence of shade and the temperature of the parking lot surface and aboveground air. In addition, shaded areas released 3% fewer emissions than unshaded areas. A hypothetical 50% tree coverage would have resulted in a 5% decrease in emissions.

Sisiopiku and Akin	2003	Pedestrian behaviors and perceptions towards various pedestrian facilities: An examination based on observation and survey data	Signalized intersections with pedestrian-activated signals and crosswalks seemed to channel pedestrian traffic, although non-compliance still occurred. The major influence on a pedestrian's decision about whether or not to cross at a designated crossing was observed to be the proximity between the crossing and the desired destination. Physical barriers were found to dissuade pedestrians from crossing in certain locations. Observations of driver behavior revealed a significant failure to yield to pedestrians, suggesting a need for further intervention to encourage yielding.
Souleyrette et al.	2003	Angle parking on Iowa's Low Volume Primary Extensions in Small Towns	Diagonal parking was found to similar to parallel parking with regard to crash propensity. In addition, fewer crashes occurred in areas with parking than without, suggesting a traffic calming benefit associated with parking.
Southworth	2005	Designing the Walkable City	Walkable neighborhoods were found to have the following qualities: linkage to a network of paths or sidewalks along streets; paths connected to other transportation modes, such as the bus; paths that are safe from traffic and crime; pedestrian-scaled details such as paving, landscaping, and lighting; enough room to comfortably accommodate 2-3 people walking side-by-side; and a surface smooth enough for a wheelchair to easily roll over it.
St. Martin et al.	2007	The Safety Effects of Urban Principal Arterial Streetscape Redevelopment Projects Including Street Trees: A Context-Sensitive Case Study	Increased frequency of access points was positively associated with increased crash rates. Shoulders wider than 3 ft. were positively associated with decreased crash frequencies. Bus stops without pullouts were positively associated with increased crash rates, but bus stops with separate loading areas were associated with lower crash frequencies. Landscaping and tree planting were associated with mixed results, with severe crashes decreasing and side-swipes and left-turn crashes increasing post landscaping improvements.
Sullivan and Daly	2005	Investigation of Median Trees and Collisions on Urban and Suburban Conventional Highways in California	The presence of large trees in curbed central medians was positively associated with increased frequency and severity of left-side accidents, but with decreased frequency of head-on and broadside collisions.

Tilahun et al.	2007	Trails, lanes, or traffic: Valuing bicycle facilities with an adaptive stated preference survey	A model of stated preferences used to predict cycling behavior found that, on average, respondents were willing to travel farthest on an alternate facility if their other option was a road with no bike lane and on-street parking. For example, subjects were willing to travel approximately 23 more minutes to an off-road facility if it was available and the other option was mixed traffic and on-street parking. All facility improvements were found to positively and significantly influence participants' choices to some degree, although the presence of a bicycle lane generally impacted a person's choice more than the elimination of parking or the presence of an off-road facility. The model also indicated that cyclists and non- or would-be-cyclists tend to prefer the same facilities.
Topp	1990	Traffic Safety, Usability and Streetscape Effects of New Design Principles for Major Urban Roads	In one case study, the elimination of street markings combined with the introduction of a pedestrian island reduced pedestrian accidents by 80%. In other cases, the combination of a center median and a reduction in posted speed was found to contribute to safety. The reduction of perceived roadway width was associated with lower automobile speeds.
Tudor-Locke et al.	2001	Active Commuting to School - An Overlooked Source of Children's Physical Activity?	Physical education in school should be supplemented by active travel to school in order to help children attain their daily physical activity quotient.
Van Houten et al.	1998	Use of Signs and Symbols to Increase the Efficacy of Pedestrian-Activated Flashing Beacons at Crosswalks	Driver yielding was observed to increase by 10% with the addition of either an illuminated pictograph near a standard pedestrian crossing sign, or a sign 50 meters before the crosswalk with requesting drivers to yield to pedestrians. With the installation of both of the pictograph and the yield sign, driver yielding increased 20%.
Whitehead	2006	The Effect of Urban Quality Improvements on Economic Activity	The addition of urban quality improvements that promote pedestrian activity was found to have a small but significant positive effect on workers and businesses, as well as to positively impact retail activity and rents. However, a marginally negative impact was found for total city center employment due to the potential for increased congestion.

Whitlock and Weinberger Transportation, Inc.	1998	An Evaluation of a Crosswalk Warning System Utilizing In-Pavement Flashing Lights	In-pavement crosswalk flashers at uncontrolled intersections were found to enhance driver awareness of crosswalks, especially during darkness, fog, rain, or other adverse weather conditions. The lights were found to work best in locations with approximately 100 pedestrians/day, and pedestrians seemed to prefer automatic activation, rather than pedestrian activation.
Wolf	2005	Business District Streetscapes, Trees, and Consumer Response	Preference ratings were found to increase steadily with the presence of trees in the photos. The most highly preferred business streetscapes had ratings comparable to those of forested and outdoor recreation areas. The presence of trees seemed to engender positive judgments about maintenance, even when compared to other well-maintained places. Tree presence was also found to reflect well on the merchants and the quality of their products. Respondents indicated a general willingness to travel further to get to, visit more often, and pay more for parking at locations with trees versus without them.
Wolf	2004	Trees and Business District Preference: A Case Study of Athens, Georgia, U.S.	Higher ranked photos consistently had a great tree presence, with higher response values associated with larger trees and increased presence. The lowest ranked images contained only man-made structures. Over 25% of the respondents commented on the benefits of the trees in an open comment section, and over 18% requested additional trees in the area.
Xiao and McPherson	2002	Rainfall Interception by Santa Monica's Municipal Urban Forest	Broadleaf evergreens provided the most rainfall interception, at about 60% of the rain falling on the tree. Conifers absorbed the next highest amount, at 23%. The urban forest in Santa Monica was estimated to intercept 1.6% of the total annual precipitation, and save the city $110,890 ($3.60/tree) in stormwater treatment and flood control costs.

Xing et al.	2008	Factors Associated with Bicycle Ownership and Use: A Study of 6 Small U.S. Cities	This research found that individual and social environment factors were more influential on the choice to bicycle than physical environment factors. For example, perceptions of bicycling safety were associated with frequency of cycling. However, these two categories are not completely discrete. A separate model in the same study suggested that for each additional mile of bicycle lane in a city, people were 5% more likely to own a bicycle and to have ridden it in the 7 days prior to the survey.
Zabinski et al.	2003	Overweight Children's Barriers to and Support for Physical Activity	Body-related barriers were the most frequently identified barriers for overweight children, in comparison with non-overweight children. Overweight girls also frequently reported convenience barriers to physical activity, as well as resource and social barriers.
Zacharias	2001	Pedestrian Behavior and Perception in Urban Walking Environments	Walking is encouraged by visual complexity and spatial differentiation, as well as a comfortable environment. Lower levels of motor vehicle traffic and corresponding slower speeds also tend to contribute to a more pleasant walking experience. Connectivity has also been found to be an important influence for walking. Street lighting and furnishings are also related to a person's choice to walk.
Zegeer et al.	2005	Safety Effects of marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report	Marked crossings may lead to a false sense of security for pedestrians crossing multilane roads with high traffic and high speeds, so they should be supplemented with other crossing treatments. Raised medians and crossing islands were associated with significantly lowered pedestrian crash rates on multilane roadways, in contrast to non-raised or painted medians. The researchers concluded that marked crosswalks should be supplemented with traffic calming and/or signalization in each of the following situations: 1) where speed limits exceed 40 mph; 2) on two-lane roadways with ADT > 12,000; 3) on multilane roadways without a raised median/crossing island and an ADT > 9,000; 4) on multilane roadways with a raised median/crossing island and an ADT > 15,000.

LIMITED ACCESS HIGHWAYS

Reference	Year	Title	Findings / Summary
Mok and Landphair	2003	Parkways or Freeways: Safety performance linked to Corridor Landscape Type	Parkway sections characterized by grassy shoulders and median trees within 30 ft. of the travelway were compared with parallel freeway sections characterized by paved shoulders, concrete barriers, and extended vegetation in clear zones. Nine of the 12 parkway sections were found to be safer as measured by the fatal accident rate; 10 of the parkway sections had a lower accident cost than the comparison sections.
Wolf	2003	Freeway Roadside Management: The Urban Forest Beyond the White Line	Settings with natural vegetation scored consistently higher than non-vegetated settings, and respondents overwhelmingly preferred trees and vegetation. There is evidence that drivers pay attention to their surroundings while driving, indicating that the presence of landscaping could positively affect driver behavior.

LIMITED ACCESS HIGHWAYS/RURAL HIGHWAYS

Reference	Year	Title	Findings / Summary
Richter et al.	2006	Speed, Road Injury, and Public Health	In contrast to European practices, the United States has maintained high speed limits on highways, leading to thousands more automobile fatalities.
Van der Horst and de Ridder	2007	The Influence of Roadside Infrastructure on Driving Behavior: A Driving Simulator Study	Drivers tended to position their vehicles closer to the right-hand side of the road when a shoulder was present than when there was no shoulder. Driving speed was significantly faster along roadway stretches with gray barriers as opposed to black/white striped barriers. Trees located 6.6 feet from the roadway were associated with significantly slower driver speeds and drivers positioning their vehicles further away from the right side of the road.

LIMITED ACCESS HIGHWAYS/RURAL HIGHWAYS/ARTERIALS

Reference	Year	Title	Findings / Summary
Brewer et al.	2001	Geometric Design Practices for European Roads	Examined European use of "environmental reference speed" via design elements to guide driver behavior.
Cackowski and Nasar	2003	The Restorative Effects of Roadside Vegetation: Implications for Automobile Driver Anger and Frustration	Participants' levels of frustration tolerance were higher after watching natural scenes versus urban driving scenes.
Cleven and Blomberg	2007	A Compendium of NHTSA Pedestrian and Bicyclist Research Projects: 1969-2007	Right-turn-on-red maneuvers were initially associated with an increase in vehicle crashes with pedestrians and bicyclists. Follow-up research concluded the same thing, although not much was done to redress the problem. More current research is needed to update the field on the subject, and to examine the effectiveness of treatments designed to reduce the conflicts.
Daniel et al.	2005	Effectiveness of Certain Design Solutions on Reducing Vehicle Speeds	Roundabouts were found to be particularly effective at calming traffic. Roadway narrowing through the installation of a center median was also found to be effective, in contrast to chicanes, which were associated with mixed findings. Speed humps were identified as the most consistently effective traffic calming measure over a variety of studies.
Hunt	2007	Influences on Bicycle Use	Stated preference surveys for cyclists revealed that cyclists are more attracted to shorter length trips, suggesting that an increase in direct connectivity could encourage cycling trips. In addition, the respondents demonstrated a clear preference for bicycle facilities. The model indicated that cyclists preferred bicycle lanes to the extent that they would trade 4.1 minutes in a bicycle lane for each single minute they would have to spend in mixed traffic; for bicycle paths, the ratio was 2.8:1. The availability of secure bicycle parking was also found to influence the decision to bicycle.
Kaplan	1995	The Restorative Benefits of Nature: Toward an Integrative Framework	Kaplan identified "directed attention fatigue" as a consequence of over-concentration during tasks that may not feel physical taxing, and suggested providing landscaping to engage and "fascinate" the mind.

Lee and Mannering	1999	Analysis of Roadside Accident Frequency and Severity and Roadside Safety Management	Wider lanes and wider shoulders were positively associated with run-off-roadway crashes in urban areas, while increased median width and number of isolated trees, miscellaneous fixed objects, and sign supports were negatively associated with such crashes. In rural areas, the findings were often reversed: the number of isolated trees, higher speed limits, and steeper cut side slopes were positively associated with run-off-roadway crashes; median width, distance from outside shoulder edge to guard rail, and increased shoulder width were negatively associated with such crashes.
Litman	2008	Barrier Effect	The "barrier effect", which tends to discourage walking, continues to exist in cities where physical structures or high traffic volumes separate pedestrians from desirable destinations. This is often the result of a tendency to undercount pedestrian trips, and therefore fail to plan for them. It becomes a self-fulfilling prophecy that failing to plan for pedestrian activity leads to fewer pedestrians, which further decreases the likelihood of such activity.
Maller et al.	2005	Healthy nature healthy people: 'contact with nature' as an upstream health promotion intervention for populations	Contact with nature was found to reduce stress and contribute to sustained interest, attention, and wakefulness. In addition, negative emotions were found to be reduced after contact with nature.
Mannering	2008	Speed limits and safety: A statistical analysis of driver perceptions	Driving speed is often more associated with fear of getting caught rather than the posted speed limit. Strategies supplementary to the posted speed limit are necessary to encourage proper driving speed.

McPherson et al.	2002	Western Washington and Oregon Community Tree Guide: Benefits, Costs, and Strategic Planting	Small trees were associated with annual net benefits of $11.73 if private, and $5.73 if public. Medium trees were associated with annual net benefits of $29.16 if private, and $23.30 if public. Large trees were associated with annual net benefits of $51.46 if private, and $46.82 if public. Over a 40-year period, planting 50 large trees, 30 medium trees, and 20 small trees was projected to benefit an area by $143,084 in energy savings, air pollution capture, and stormwater runoff reduction.
Neuman et al.	2003	Guidance for the Implementation of the AASHTO Strategic Highway Safety Plan: Volume 3: A Guide for Addressing Collisions with Trees and Hazardous Locations	Eight percent of all collisions in 1999 involved trees, and 90% of those collisions occurred on two-lane roads. Just 24% of the collisions with trees occurred in urban areas, half of which happened on curved sections of the roadway.
Parsons et al.	1993	The View from the Road: Implications for Stress Recovery and Immunization	Participants exhibited negative emotional responses and prolonged stress-recovery periods after viewing drives dominated by man-made artifacts such as utility lines, buildings, and billboards. Driving scenes through park-like areas seemed to elicit the least effect on blood pressure and promote the quickest recovery from stress and highest scores on subject tests.
Pretty	2004	How nature contributes to mental and physical health	A strong correlation was found between people viewing or being present in nature and feeling healthier. Patients' healing processes were found to be benefited by time spent in gardens or atriums, or even looking out at nature versus an urban view.
Thompson et al.	2004	Iowa, U.S., Communities Benefit from a Tree-Planting Program: Characteristics of Recently Planted Trees	The trees planted in this study saved their communities as a whole $117.30/year for their removal of particulate matter and air pollutants alone. Were the trees to all grow to a girth of 2.5 feet diameter at breast height, nearly $7,742 would be saved for the communities as a whole.

Ulrich	1986	Human Responses to Vegetation and Landscapes	Humans were found to have a strong preference toward nature, particularly when trees are present. Urban scenes were also found to be more pleasing when trees were present. Participants' self-ratings after viewing natural scenes were more positive than ratings after viewing urban scenes. Recordings of brain activity revealed higher alpha-wave amplitudes while subjects viewed trees and other vegetation in comparison to urban scenes. Driver preference was also linked to landscaping versus urban scenes.

LIMITED ACCESS HIGHWAYS/ARTERIALS

Reference	Year	Title	Findings / Summary
Akbari et al.	2001	Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas	Urban heat island effects have contributed to warming cities' temperatures by 1–6 degrees F since 1940. An estimated 5–10% of the current urban electricity is in response to this increase in temperature. Planting trees and painting surfaces light colors were strategies promoted to reduce the urban heat island effect. These strategies were projected to eventually decrease air conditioning usage by 20% if done comprehensively, resulting in energy savings and reduced emissions from power plants.
Dwyer and Miller	1999	Using GIS to Assess Urban Tree Canopy Benefits and Surrounding Greenspace Distributions	Energy savings to the tune of $126,859 were calculated due to tree shading in the study area. Stormwater runoff analysis found that the areas with the highest amount of tree canopy experienced the least amount of runoff.
Gonzales et al.	2004	2002 Bicycle Transportation Survey: Developing Intermodal Connections for the 21st Century	Users indicated a strong affinity for the off-road bicycle paths in Rhode Island, but also desired on-road facilities that connected people from their homes or work to the paths. Many participants indicated that they used the paths as a way to exercise, suggesting a niche for such facilities. Participants were also found to spend an average of $1-5 each time they used the paths, indicating a small monetary benefit for the community.

Koren and Butler	2006	The Interconnection Between the Built Environment Ecology and Health	The literature review suggested several connections between physical health and the built environment, including air pollutants and asthma, heat island effects and increased risk of heat stroke, and risk to local water sources.
McPherson	1992	Accounting for Benefits and Costs of Urban Greenspace	Mesquite trees were found to annually intercept 35 lbs of dust and 73 gallons of stormwater runoff each year, in addition to shade and lowered temperature. The total savings attributed to each tree was $29/tree/year, with a benefit: cost ratio of 2.6:1.
McPherson and Simpson	2003	Potential Energy savings in Buildings by an Urban Tree Planting Program in California	California's 177 million energy-conserving urban trees reduce annual electricity use for cooling by 6,407.8 GWh ($971.6 million savings for consumers). The researchers estimated that planting 50 million trees to shade east and west walls of residential buildings were produce a total cooling savings of 46,891 GWh, or $3.6 billion, after 15 years. It would also offset 60% of the increased electricity consumption associated with California's projected 8 million new residents.
McPherson et al.	1999	Benefit-Cost Analysis of Modesto's Municipal Urban Forest	Modesto's urban forest was found to benefit the Modesto residents by about $5 million ($54-57 per person per tree) in savings for air quality, stormwater runoff reduction, energy savings, and aesthetics.
McPherson et al.	2005	Municipal Forest Benefits and Costs in Five US Cities	Each city analyzed experienced a net benefit from its urban forest. The lowest savings amount accrued was $31/tree in Glendale (benefit: cost ratio of 1.37:1); the highest savings amount was $89/tree in Berkeley (benefit: cost ratio of 3.09:1).
Rietveld and Daniel	2004	Determinants of bicycle use: do municipal policies matter?	Analysis of policies in cities with high percentages of bicyclists suggested a strong positive correlation between government policy and increased bicycle use. Specifically, making a bike trip 10% faster than the same trip via auto increases bike usage by 3.4%; and reducing stops by 30% per km leads to a 4.9% increase in bicycling usage. Reducing the chance of bicycle theft and increasing the cost of driving also lead to increased bicycle usage.

Simpson	1998	Urban Forest impacts of Regional Cooling and Heating Energy Use: Sacramento County Case Study	The urban forest of Sacramento was estimated to save the area $20 million through shading and reduction of windspeed and air temperature. Most of this is due to reduced cooling costs.
Souch and Souch	1993	The Effect of Trees on Summertime Below Canopy urban Climates: A Case Study Bloomington, Indiana	Sites with trees were found to be significantly cooler than a control site of irrigated turf, even when the trees were shading concrete. In comparison to the area underneath the trees, however, the edges of trees planted over concrete were found to be warmer than the control site.
Streiling and Matzarakis	2003	Influence of Single and Small Clusters of Trees on the Bioclimate of a City: a Case Study	As the number of trees in an area increased, the temperature was found to decrease. On average, air temperature under a single tree is approximately 0.5 degrees F higher than the temperature detected under a cluster of trees. Regardless, a human comfort index suggested a much higher comfort level in the area with trees as compared to the area with trees. The trees were also shown to reduce nitrogen oxides and ozone by 45% and 55%, respectively, on the days measured.
Wardman et al.	2007	Factors Influencing the Propensity to Cycle to Work	Revealed and stated preferences were gathered from cyclists in the U.K. to build a model predicting bicycling behavior. The data suggested that providing cycling facilities were encourage a higher bicycling modeshare - up to a 55% increase with separated cycleways, which were also projected to reduce car usage by 3%. Shower and indoor and outdoor parking facilities were also found to be prized by cyclists.
Wolf and Bratton	2006	Urban Trees and Traffic Safety: Considering U.S. Roadside Policy and Crash Data	Far less than 1% of U.S. household trips in 2001 resulted in a crash with a tree. In 2002, trees were involved in less than 1% of urban collisions, and less than .001% of fatal urban collisions. The average speed of collisions involving trees was 14 mph faster than the average speed of all crashes combined.

RURAL HIGHWAYS

Reference	Year	Title	Findings / Summary
Hunter	1998	An Evaluation of Red Shoulders as a Bicycle and Pedestrian Facility	Red-painted shoulders on a two-lane rural road were viewed positively by 86% of surveyed cyclists, 79% of whom reported feeling safer using them. Video showed that 86% of cyclists used the shoulders at least part time while riding the roadway, with 80% using them the entire time they were available. Although drivers were observed passing cyclists with more space when there was no painted shoulder, this often led to conflicts with oncoming traffic, potentially compromising safety for all on the roadway.
Karlaftis and Golias	2002	Effects of Road Geometry and Traffic Volumes on Rural Roadway Accident Rates	AADT was found to be the most important factor for collision rates on both two-lane and multilane rural highways. Controlling for AADT, however, revealed that median width, followed by access control, was the most important factor on multilane highways. For two-lane highways, vehicle travel lane width , followed by variables related to roadway pavement conditions, was the most important factor in collision rates after controlling for AADT.
Steyvers and DeWaard	2000	Road-edge Delineation in Rural Areas: Effects on Driving Behavior	Drivers on edge-lined rural highways were found to drive more closely to the center of the road and more slowly than those on axis-lined highways. Driver speed was lowest on the unlined highway. The various lining conditions were not found to contribute to driver stress, although driver steering was found to be better on the lined roadways.
Wolf	2004	Nature in the Retail Environment: comparing Consumer and Business Response to Urban Forest Conditions	The combined lowest preference score went to the "sparse vegetation" category, while the highest preference score was given to the "formal foliage" category.

RURAL HIGHWAYS / ARTERIALS

Reference	Year	Title	Findings / Summary
Garder et al.	2002	Traffic Calming of State Highway Application New England	In areas with low ADT (i.e., ≤ 15,000), well-designed, circular intersections have slowed traffic and reduced crashes by 50-90% in certain cases. A review of roundabouts in New England revealed that they were associated with significantly fewer fatal and serious injury crashes post-installation. Traffic calming measures such as bike lanes, medians, speed tables, and raised crosswalks have led to reductions in speed of up to 15 mph in Portland, OR.
Ossenbruggen et al.	2001	Roadway safety in rural and small urbanized areas	In this case study comparing a strip commercial site with a rural residential site and a village "main street" site, the highest number of overall crashes and injury crashes occurred at the strip commercial site. The lowest number of both overall crashes and injury crashes occurred at the village "main street" site, even after controlling for traffic exposure. The high number of pedestrian injuries in the rural residential and strip commercial sites was blamed in part on a lack of sidewalk facilities to offer protected walking space.
Ivan et al.	2001	Finding Strategies to Improve Pedestrian Safety in Rural Areas	Driver speed was found to be inversely correlated with the probability of yielding to a pedestrian in a crosswalk, suggesting that supplementary treatments will be necessary to slow drivers down in order to facilitate yielding. A second part of the study found a positive association between higher-density residential areas and lower injury severity, as compared to lower residential areas, which likely had higher average vehicle speeds.