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Agreement T2695, Task 18
Landscape Median

**IN-SERVICE EVALUATION OF MAJOR URBAN
ARTERIALS WITH LANDSCAPED MEDIANS—
CONDITIONS AS OF 2004**

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16. ABSTRACT <p>Arterials such as State Route (SR) 99 north and south of Seattle have characteristics that are considered by many cities to be undesirable. In response, several cities are implementing redevelopment plans to increase road safety, create a more aesthetically pleasing local environment, and enhance the economic vitality and attractiveness of the communities. The cities' redevelopment proposals for SR 99 and other state routes include landscaped medians, many with trees placed close to the roadway in either the median or shoulder areas. However, WSDOT's clear zone width criterion may not always be met when trees are placed within curbed medians. To address the desires of cities to implement aesthetic designs, WSDOT chose to adopt an in-service evaluation process that would study collision, environmental, operational, and maintenance experiences in the field.</p> <p>This report summarizes the findings of two of the 13 median treatment projects included in the in-service evaluation of alternative median treatments. It provides <i>before</i> data and condition information on all median sections, but because most of the roadway sections have only recently been improved, it provides <i>after</i> data for only two phases of improvements, those on SR 99 in the City of SeaTac. The conclusions of the before and after analysis on those two sections of roadway indicate that no dramatic changes in roadway safety have occurred as a result of the change from continuous two-way left turn lanes and limited sidewalks to a streetscape that includes full sidewalks and landscaped medians with turn pockets, and where both sidewalks and medians include small trees as part of the landscaping. While no definitive conclusions about the safety impacts of landscaped medians can be drawn at this point in the multi-year in-service evaluation, it can be said that there is no indication that the roadways are less safe than before the landscaping was planted. Therefore, it is recommended that the current in-service evaluation be continued as planned.</p>					
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EXECUTIVE SUMMARY

This report documents the effects on roadway safety performance of landscaped medians and other streetscape improvements as implemented on SR 99. Findings contained in this report are based exclusively on the analysis of a before-and-after study of streetscape improvements made in phases 1 and 2 of a route improvement effort in the City of SeaTac. The full report also describes the *before* conditions at several other locations that have recently undergone streetscape improvements but for which sufficient *after* data are not yet available for analysis. Future updates to this report will include results from additional study sections as data from those locations become available.

Findings from SeaTac phases 1 and 2 analyses are somewhat inconclusive. No dramatic changes in accident frequency or severity were observed. Accident frequency for the combined study area decreased slightly, but accident frequency within the SeaTac Phase 2 road segment actually increased slightly. Neither change was statistically significant. SR 99 through these road segments remains a high accident location. A shift in accident locations did occur, with fewer mid-block accidents occurring, while the number of accidents at intersections increased. In particular, U-turn accidents increased following the projects' construction, from four accidents to 35 within three years. These changes relate directly to the access control effects of the medians that were constructed. Additional analysis of these intersection accidents is currently under way at the Washington State Department of Transportation (WSDOT).

Of significant interest in this study was the fact that the City of SeaTac planted street trees in these two roadway segments as part of streetscape improvements. Trees were planted both in sidewalks and in raised medians. The presence of trees had a mixed but limited effect on accident rates and statistics. Fixed-object accidents decreased in the Phase 1 roadway segment but increased in the Phase 2 segment. Neither change was statistically significant. When trees were involved in accidents, the small size of the trees appears to have limited the severity of the resulting accidents, increasing the likelihood that they would be classified as "property damage only" accidents. However, the involvement of the trees in the accidents does raise some concern that as the trees grow larger, accident severity may increase to the point at which street trees increase the

potential for more severe accidents. In addition, SeaTac did discover that placing trees in narrow medians and near road segments with turning movements resulted in high levels of tree strikes. As a result, SeaTac decided to no longer place trees in these locations.

PROJECT INTRODUCTION

Legacy arterials such as State Route (SR) 99 north and south of Seattle are unique in that they play multiple roles. SR 99 performs a significant regional mobility function as an alternative, high capacity route parallel to Interstate 5. It simultaneously provides access to local businesses, services, and residents. It is considered by many cities to provide a main street function to the surrounding area. This combination of local and regional functions creates a unique challenge, as the roadway attributes that allow a roadway to move large numbers of vehicles quickly (regional mobility) are often not those required to provide a safe, pleasant “main street” environment for a city, and vice-versa.

Numerous cities are adopting comprehensive plans that include redevelopment of the land use along these highways, and incorporated into those redevelopment plans are significant changes to the design of the roadway itself. The goals of the cities are to create a livable community and to improve the quality of life of the nearby residents and road users. However, these objectives must be achieved while maintaining the regional mobility function of the facility. To meet these challenges, many of the cities have adopted in their redevelopment plans measures intended to increase the safety of the road, create a more aesthetically pleasing local environment, and enhance the economic vitality and attractiveness of the surrounding communities, all while maintaining vehicle throughput.

One of the main features of the roadway redesign is a change from roads with continuous two-way left turn lanes and unrestricted land access to roads with raised (and sometimes landscaped) medians with protected left turn pockets, various pedestrian treatments, and greater access control to the abutting land. In some cases, cities wish to place small trees within the landscaped medians and new sidewalks.

This report documents the results of in-service evaluations of the effects of these improvement efforts. The report itself is meant to be a living document. It will be

updated annually for the next several years to reflect what happens along a series of legacy arterials on which physical changes are being implemented.

PROJECT BACKGROUND

A fundamental mission of the WSDOT is to provide mobility while protecting the safety of the traveling public through good road design. An extensive body of research is the basis for determining appropriate designs and standards adhered to by WSDOT for particular roadway and roadside characteristics. Prominent among these standards is the clear zone. The clear zone defines the width of the roadside that should be clear of fixed objects.

The cities' redevelopment proposals for SR 99 and other state routes include landscaped medians, many with trees placed close to the roadway in either the median or shoulder areas. When trees are placed within curbed medians or sidewalks, these designs may not always meet WSDOT's current clear zone width criteria.

To determine whether landscaping could be implemented that both addressed the desires of cities to implement more aesthetically pleasing designs while also remaining safe, WSDOT chose to adopt an in-service evaluation process that would apply real-world experience to a broad range of collision, environmental, operational, and maintenance situations that could not be fully replicated in a traditional test environment. WSDOT initiated the In-Service Evaluation of Landscaped Medians Agreement with cities along SR 99, in part, to study the overall effects of the various "context sensitive" designs these cities wished to implement.

The objective of the research was to determine whether the aesthetic and quality of life goals of the cities conflict with the safety considerations of foremost importance to WSDOT. The results of this evaluation will be used to better understand the overall impacts and benefits of these designs. The evaluation will also likely assist in the development of new urban design policy by presenting to decision-makers quantitative and qualitative measures of the impacts of design tradeoffs within the urban context.

One of the significant motivations for the SR 99 improvement projects has been the accident rates experienced along these routes in recent years. When compared to other routes of the same classification, SR 99 has some of the highest accident rates in the state. Furthermore, the severity levels of the resulting injuries are also high. Of specific

interest, and of primary concern in this report, is whether the aesthetically pleasing landscaped designs change the accident rates and characteristics of these roads.

STUDY LOCATIONS

The In-Service Evaluation of Landscaped Medians Agreement was formed between WSDOT and cities along SR 99 that intended to plant trees within curbed medians. This agreement was based on the desire to implement safe designs, particularly in cases where the proposed designs deviated from WSDOT's customary practice and official design standards. The cities that entered into in-service agreements with WSDOT, and are thus part of the entire evaluation process, are Federal Way, SeaTac, and Shoreline. Data from roadway projects in the cities of Kent, Des Moines, Mukilteo, and Kenmore, as well as on SR 99 in an unincorporated section of King County, are also being evaluated for different parts of the analysis but are not formally part of the in-service evaluation agreement developed by WSDOT. These additional jurisdictions participated in this study simply because of their interest in evaluating the impacts of their streetscape redevelopment projects and the overall effectiveness of the improvements installed along these high-speed urban corridors. The cities that did not have an In-Service Agreement with WSDOT selected design criteria that did not significantly deviate from customary design practices.

Segments of roadway within these different jurisdictions are referred to within this study by names referring to the phasing of the construction changes. Thus "SeaTac Phase 1" is that segment of SR 99 that was included in the first construction improvement phase of the SR 99 redevelopment effort in the City of SeaTac. "SeaTac Phase 2" is the second segment of roadway improved, not a second phase of improvements to the roadway already improved as part of Phase 1.

Changes implemented by the cities included improvements in three general areas: roadway, roadside, and pedestrian facilities. Improvements to the roadway commonly included converting two-way left turn lanes into landscaped medians with left turn/U-turn pockets, widening the roadway, adding business access and transit (BAT) lanes through some project sections, installing street lighting, and making signal improvements. Improvements to the roadside environment frequently included consolidating and defining driveways/access points, placing utilities underground, and upgrading

stormwater collection and detention facilities. Pedestrian-oriented improvements frequently included installing sidewalks and pedestrian-scale features such as better lighting, improved pedestrian crossing points, new or improved transit stops, and aesthetic treatments such as landscaping and street trees.

Different treatments were proposed and performed by each of the cities. Differences of particular significance to this research included various median widths, median lengths, barrier types, and landscaping treatments. All of the cities desired to improve the safety and livability of their corridors and selected designs that they believed would meet the needs of the corridors' varied users without introducing unacceptable risks to any user group.

Some of the benefits expected from the type of redevelopment proposed in these plans include reductions in turning movement conflicts from improved access control measures (median barriers, driveway delineation and consolidation); capacity improvements from additional lanes and reduced access points; safety improvements for pedestrians and transit users; and smoothed traffic flow, with the potential for reductions in speeds due to the visual perception of a narrower roadway from the roadway delineation provided by the median and roadside trees.

Some of these elements and effects may be viewed as presenting drawbacks. For example, although some stakeholders may view reduced speeds as a benefit to safety and livability, WSDOT views significant reductions in speeds as a drawback, given that one of its primary objectives is to design and operate highway facilities that function efficiently. Any reduction in speed may translate into reduced traffic flow, and thus a less efficient facility. Other drawbacks resulting from the streetscape redevelopment plans include potential increases in accidents at intersections, conflicts at concentrated locations such as mid-block left turn lanes, and the potential safety impacts of placing trees within the Design Clear Zone (DCZ). These potential impacts include an increase in the likelihood of severe injuries involving tree collisions, given the speed of the facility (40-45 mph), the effects that trees may have on pedestrian crossing behavior, and the impact the trees may have on drivers' sight distances. The maintenance of trees required to sustain the desired effects is also a consideration that must be addressed. In brief, each

of the included elements presents varying impacts that must be balanced to achieve a safe, efficient, and attractive facility that meets the needs of the varied stakeholders.

METHODOLOGY

Data used for this study come from numerous sources. Given that the purpose of this research is to quantify some of the safety tradeoffs made within the urban highway context, the data needs were initially defined to include accident experience, roadway geometries, traffic characteristics, level of access, and specific elements related to the median and roadside trees.

The research for this project is occurring in two distinct quantitative forms: 1) the analytical process of comparing accident frequencies and severities and determining significant differences, and 2) the development of statistical models to explain the factors that contribute to the frequency or severity of accidents.

The initial analysis consists of a before/after comparison of the projects, evaluation of significant changes before and after project construction, and comparison to similar facilities statewide. This part of the analysis has been completed for the SeaTac Phase 1 and Phase 2 projects, while the *before* conditions are presented for all but two of the remaining sections. The *after* phase of the analysis, which will allow for meaningful discussions pertaining to changes in the level of safety within each project area, will be conducted in subsequent years, as specified in each project description. Comparisons are drawn between some of the project sections to highlight where there appear to be critical safety concerns.

The statistical analysis consists of developing explanatory models that can compare the factors contributing to the frequency and severity of accidents before and after the project construction. As of this writing, most projects selected for analysis had only been recently finished or were still under construction, so *after* data for comparison and analysis of these projects will not be available for several years. Consequently, in this report the analysis of changes in safety due to the streetscape improvements has only been conducted for the SeaTac phases 1 and 2 project areas.

In addition, SeaTac has supplied supplementary maintenance information about median intrusions and tree maintenance activities. The frequency of tree incidents offers qualitative insights into the potential future impacts of median and roadside trees once

they have reached maturity (specifically, once they have reached the 4-inch diameter that WSDOT specifies as a fixed object).

FINDINGS

The SeaTac phases 1 and 2 analyses showed that, prior to the streetscape improvements, SR 99 was a high-accident corridor (HAC) in comparison to other similarly classified highway facilities in Washington State. Following the construction of the Phase 1 and Phase 2 streetscape projects, SR 99 remained an HAC. The accident rate for the combined SeaTac phases 1 and 2 projects decreased; however, there is little other evidence to suggest an improvement in the overall safety within these project areas. In fact, a slight, statistically insignificant, increase in the accident rate for the Phase 2 project compared to the decrease shown in the Phase 1 roadway section showed that the changes in accident frequency were mixed.

The locations of accidents did shift significantly within the SeaTac Phase 1 and Phase 2 projects. Before the projects were constructed, more accidents occurred at mid-block locations than following construction. Following the project's construction, U-turn accidents increased from four accidents to 35 within three years. This shift in accident locations was expected, given the extent of turning movement restrictions and access controls imposed by the installed medians. However, the size of the increased accident rate at the intersections was disappointing.

The accident frequency models indicated that prior to redevelopment, geometric factors such as wide shoulders, access control, and curbs separating lanes tended to reduce the frequency of accidents, whereas bus stops, some turn lanes, intersections, and horizontal curves tended to increase the number of accidents. The most significant contributing factors to increasing accident frequency did not change after the streetscape improvements; however, the models now show that lane separation (curbs or medians of any width) tends to decrease accidents, and some access control measures tend to increase accidents.

Interestingly, tree variables had relatively little impact on the prediction of accident rates. In one case the number of trees was found to be statistically significant in decreasing accident rates, but the project team believes that in this case, the tree variable was acting as a surrogate for a lack of conflicting movements occurring in the affected

section of road, rather than truly reflecting the effect that trees were having on accident rates. In one other case, the presence of trees in association with driveways slightly increased accident rates. It is possible that the presence of trees caused some loss of visibility and thus increased accident potential, but it is also possible that in this case, the tree variable was acting as a surrogate for other driveway attributes.

The tree incident records indicated that vehicles collided with more than the eight trees reported in the collision records. (Unreported tree strikes are likely to occur when minor accidents occur and the involved motorists do not report those accidents.) A total of 32 additional trees were replaced in the three-year analysis period as a result of unreported vehicle strikes. If the unreported tree strike incidents were included in the “fixed-object collision rate,” the rate would show a statistically significant increase from the *before* to the *after* condition. It should be noted, however, that a significant portion, but not all, of these additional trees strikes took place in the narrow median sections in which trees are no longer being placed.

The severity models indicated that trees contribute to a higher probability of an accident being a “property damage only” accident (i.e., not involving an injury or potential injury). This is likely due, in part, to the small size of trees in the study. Small trees are likely to slow vehicles, causing property damage, but not to abruptly halt out-of-control vehicles, causing serious injury. However, concern does exist that as tree width and strength grow over time, tree accident severity may increase. While the trees species planted in the streetscape were selected specifically because their trunk size would remain modest, it is recommended that the WSDOT and involved cities continue to monitor the impacts of tree strike accidents along the corridor to ensure that accident severity does not increase as the trees mature.

Pedestrian and bicyclist safety along these routes is a concern, as an important goal of the streetscape redevelopment plans is to improve the livability and “walk-ability” of the road and roadside environment. These routes are also often high transit use facilities, thus increasing the number of pedestrians walking in the streetscape environment. The SeaTac analyses indicated that the number of pedestrian and bicycle accidents decreased following construction of the Phase 1 and Phase 2 projects. Given the

low number of accidents involving bicyclists and pedestrians, we cannot determine whether this change is statistically significant.

A sidewalk impact study was conducted along the Phase 2 project area (Knoblauch 1998). This study measured the volume and activity of pedestrians in 1997 and 1998 (immediately before and after project construction). The results indicated a 15 percent increase in pedestrian volume, although it showed that this increase was not statistically significant. These data were not within the analysis timeframe established for this current analysis; however, they indicate that pedestrian usage along the SR 99 corridor did not significantly increase immediately following the Phase 2 project's construction. *Before* and *after* volumes of bicyclists were not available.

The *Bus Stop* indicator in the frequency and severity models was significant for the *before* conditions but insignificant following redevelopment. This indicates some degree of safety improvements at bus stops. The locations, characteristics, and visibility of bus stops were improved as part of these projects; improvements included moving most of them to the far side of intersections and constructing pullouts for transit vehicles.

In conclusion, the different measures of safety on SR 99 indicated some improvements for specific user groups and locations. However, the decrease in the overall accident rate and the shift in accident severities (indicating an increased probability of injury) were not shown to be statistically significant. Therefore, the effects of this type of streetscape redevelopment project cannot yet be concluded. Additional research will likely lead to a more complete understanding of the impacts of aesthetic design features and street trees installed as part of a streetscape redevelopment project within a high-speed urban corridor.

CHAPTER 1

INTRODUCTION AND BACKGROUND

Current trends in transportation design are to implement designs that are sensitive to specific conditions along the project and to the local culture and desires. “Context Sensitive Designs/Context Sensitive Solutions” (CSD/CSS) may entail implementing local design solutions that are not typical of the regional design standards and practices typically administered by the federal or state transportation agencies.

Interest has been growing in installing landscaped treatments along urban facilities with a speed limit of 35 to 45 mph as a way to enhance safety and improve aesthetic characteristics. Current design standards have been developed to enhance the safety of travelers on highways. However, strict application of these standards may preclude aesthetic treatments that are desired by the local community to improve the livability of their urban environment. The justification for deviating from some standards (such as the clear zone) in order to enhance aesthetics is the prediction that the location for which the deviations are proposed will not experience the same consequences as those in which testing has been conducted. To determine whether the consequences of deviating from the standard have been accurately predicted, accident and traffic data must be gathered and analyzed. An in-service evaluation process allows these types of projects to be constructed, with the explicit agreement that the cities will cooperate with data collection efforts as well as mitigation strategies if they are deemed necessary.

This report explains why streetscape redevelopment projects with landscaped medians are being undertaken in Washington State, who has been involved in the design and decision-making processes, and the desired outcomes from these projects. Numerous cities are undertaking projects with similar features, so each project’s background, objectives, progress, and results are discussed. This report also describes the development of a standardized framework for in-service evaluations of landscaped medians, based on appropriate performance criteria and data collection plans, to provide consistent examination of the effectiveness of the various median treatments in urban areas. Finally, the report presents the initial results from this framework at this point in time.

PROJECT INITIATION

Legacy arterials such as State Route (SR) 99 north and south of Seattle have characteristics that are considered by many cities to be undesirable. High traffic volumes, high speeds, and increasing levels of land use along these routes have led numerous cities to create comprehensive plans that include redevelopment of the highway facilities. SR 99 has a significant regional function as an alternative, parallel route to Interstate 5, while simultaneously providing access to local businesses, services, and residents. It is considered by many cities to provide a main street function to the surrounding area. This combination of local and regional functions creates a unique challenge. The goals of the cities are to create a livable community and to improve the quality of life of the nearby residents and road users. The objectives of their redevelopment proposals include increasing the safety of the road, creating a more aesthetically pleasing local environment, and enhancing the economic vitality and attractiveness of the communities. These objectives must be achieved while maintaining the regional mobility function of the facility.

A fundamental mission of the Washington State Department of Transportation (WSDOT) is to protect the traveling public through good road design. An extensive body of research is the basis for determining appropriate designs and standards adhered to by WSDOT for particular roadway and roadside characteristics. Prominent among these standards is the clear zone. The clear zone defines the width of the roadside that should be clear of fixed objects. The cities' redevelopment proposals for SR 99 and other state routes include landscaped medians, many with trees placed close to the roadway in either the median or shoulder areas. However, WSDOT's clear zone width criterion may not always be met when trees are placed within curbed medians.

To address the desires of cities to implement aesthetic designs, WSDOT could have developed a new clear zone standard for urban arterial sections by testing various median widths, tree sizes, and design features. Instead, WSDOT chose to adopt an in-service evaluation process that would apply real-world experience to a broad range of collision, environmental, operational, and maintenance situations that could not be fully replicated in a traditional test environment. WSDOT initiated the In-Service Evaluation of Landscaped Medians Agreement with cities along SR 99, in part, to study the overall

effects of various “context sensitive” designs. The objective of the research was to determine whether the aesthetic and quality of life goals of the cities conflict with the safety considerations of foremost importance to WSDOT. The results of this evaluation will be used to better understand the overall impacts and benefits of these designs. The evaluation will also likely assist in the development of new urban design policy by presenting to decision-makers the quantitative and qualitative measures of the impacts of design tradeoffs within the urban context.

PROJECT DESCRIPTION

The project sections along SR 99 that were included in the evaluation process were within the cities of Des Moines, Federal Way, Kent, SeaTac, and Shoreline. An additional section of SR 99 not within an incorporated city is also being redeveloped and was included in the evaluation. Additional projects were also included in this study, including SR 522 through Kenmore and SR 525 through Mukilteo. Each city has implemented or will implement streetscape improvement plans, many including trees within the median.

Classification and Users

State routes 99, 522, and 525 are classified as urban arterials and serve the mobility and access needs of both regional and local traffic. Each route has high traffic volumes, high speeds, and experiences accident rates involving vehicles and pedestrians that are above the statewide average for facilities of this classification. Although these corridors do not have pedestrian-friendly facilities or amenities, there is a significant level of pedestrian traffic along many sections. Much of pedestrian traffic is associated with bus routes through the corridors. Many pedestrians cross SR 99 at unmarked mid-block locations, as opposed to walking to the nearest signalized intersection. There is also a significant percentage of truck traffic with needs for safe mobility and access.

Safety, Aesthetics, Streetscapes, and Access

One of the significant motivations for these projects has been the accident rates experienced along these routes in recent years. They are some of the highest in the state in comparison to routes of the same classification. From the mid 1990s through 2002,

locations within each of the projects along SR 99 were classified as High Accident Locations, (HALs), High Accident Corridors (HACs), or Pedestrian Accident Locations (PALs) by the Washington State Accident Location and Prioritization program. This program is based on the frequency of accidents within specified distances (HAL<1 mile and HAC>1 mile) over three consecutive years for HAL and five consecutive years for HAC. Furthermore, not only is the frequency of accidents high, but so is the severity of the resulting injuries. The safety of motorized and non-motorized users has raised awareness within cities and the state DOT of the need for improvements along this corridor.

The other primary reason for undertaking these projects is the opinion that the streetscape is unattractive. The typical cross-section of SR 99 consists of five lanes, with a two-way left-turn lane (TWLTL) for a center lane. In general, within the existing project limits and conditions, the paved shoulders are wide, with sidewalks at only a few locations. Access to commercial and private properties is minimally controlled. At a few locations there is no TWLTL, or there is a low, asphalt-covered median and C-curb separating traffic. In addition, many intersections have dedicated right and left turn lanes. In general, the aspect is of a wide, uncontrolled asphalt streetscape with cars moving in every direction. There is almost no provision for the comfort, safety, and ease of pedestrians, though many pedestrians travel through and across the SR 99 corridor. The land use was primarily strip commercial development. Some of the conditions existing prior to project construction are illustrated in Figure 1-1.



Figure 1-1. SeaTac Existing Streetscape in the Early 1990s

The SR 522 streetscape through Kenmore is similar, consisting of a five- to seven-lane section. Two through lanes in each direction are continuous throughout the corridor; there are transit lanes in each direction along a portion of the highway; and there is a center, dedicated left-turn lane or TWLTL though part of the corridor. Some sections have sidewalks, but generally access is undefined and minimally controlled with a C-curb. The shoulders vary in width and are narrow through much of Kenmore. Some native trees and landscaped sections with trees exist along the roadside, and in some places the trees are close to the roadway. The characteristic development consists of strip commercial establishments, while other sections are not yet developed.

The typical SR 525 section is a two-lane, undivided highway with no access control and variable width shoulders. The sections of commercial development are more spread out than along SR 99, with some sections having a more rural or residential character. A significant portion of the traffic along SR 525 is related to the ferry dock in downtown Mukilteo.

The described section along state routes 99, 522, and 525 are incompatible with city and community comprehensive plans, and given the need for safety improvements, cities chose to initiate boulevard-type streetscape redevelopment plans. The resurgence of the boulevard street section is an attempt to create an environment that is attractive to pedestrians, smooth traffic flow and reduce vehicle speeds, and foster a sense of community. A typical element of this type of redevelopment is roadway vegetation, often consisting of street trees.

Development Plans

Changes proposed by the cities included improvements in three general areas: roadway, roadside, and pedestrian facilities. Proposed improvements to the roadway included converting two-way left-turn lanes into landscaped medians with left-turn/ U-turn pockets; widening the roadway; adding business access and transit (BAT) lanes through some project sections; installing street lighting; and making signal improvements. To improve the roadside environment, consolidating and defining driveways/access points; undergrounding utilities; and upgrading storm water collection

and detention facilities were proposed. To enhance the pedestrian zone, cities proposed installation of sidewalks and pedestrian-scale features through the corridors. These features included pedestrian lighting, improved pedestrian crossing points, new or improved transit stops, and aesthetic treatments such as landscaping and street trees.

Different treatments were proposed by each of the cities. Differences of particular significance to this research included median widths, median lengths, barrier types, and landscaping treatments.

Table 1-1 details the project limits and specific roadway changes for each of the projects included in this evaluation. Table 1-2 lists the type of project evaluation and the timeline for project completion and analysis. They both present the projects in order of increasing milepost, with state routes 522 and 525 following SR 99.

All of the cities desired to improve the safety and livability of their corridors and selected designs that they believed would meet the needs of the corridors' varied users without introducing unacceptable risks to any user group. The In-Service Evaluation of Landscaped Medians Agreement was formed between WSDOT and cities along SR 99 that intended to plant trees within curbed medians. This agreement was based on the desire to implement safe designs, particularly in cases where the proposed designs deviated from WSDOT's customary practice and official design standards. The "Study Type" column in Table 1-2 reflects the distinction between projects that were part of the In-Service agreement and those that participated in the landscaped median evaluation simply because of their interest in evaluating the impacts of their streetscape redevelopment projects and the overall effectiveness of the improvements installed along these high-speed urban corridors. The cities that did not have an In-Service Agreement with WSDOT selected design criteria that did not significantly deviate from customary design practices. Each of these projects is described in detail in Chapter 4.

Table 1-1. Individual Project Features

	Limits	SRMP	Existing	Proposed Conditions
SeaTac				
Phase 4	S 216 th -200 th	[16.52-17.52]	4 lanes +TWLTL	5 lanes (1 BAT) turn pockets, median, trees
Phase 2	S 200 th -188 th	(17.52-18.35]	4 lanes +TWLTL	5 lanes (1 BAT) turn pockets, median, trees
Phase 1	S 188 th -170 th	(18.35-19.48)	4 lanes +TWLTL	5 lanes (1 BAT) turn pockets, median, trees
Phase 3	S 170 th -152 nd	[19.48-20.66]	4 lanes +TWLTL	5 lanes (1 BAT) turn pockets, median, trees
Federal Way				
Phase 1	S 324 th -312 th	(9.68-10.59]	4 lanes +TWLTL	6 lanes (2 BAT) turn pockets, median, trees
Phase 2	S 340 th -324 th	(8.64-9.68]	4 lanes +TWLTL	6 lanes (2 BAT) turn pockets, median, trees
Des Moines				
Phase 1	SR-516-216 th	[15.49-16.51]	4 lanes +TWLTL	6 lanes (2 BAT) turn pockets, median barrier, trees
Kent				
Phase 1	S 272 nd -252 nd	(12.92-14.24]	4 lanes +TWLTL	6 lanes (2 BAT) turn pockets, median, shrubs
Phase 2	S 252 nd -SR-516	(14.24-15.49)	4 lanes +TWLTL	6 lanes (2 BAT) turn pockets, median, shrubs
Shoreline				
Phase 1	N 145 th -165 th	[40.47-41.48]	4 lanes +TWLTL	6 lanes (2 BAT) turn pockets, median, trees
WSDOT- unincorporated King County				
Phase 1	S 284 th -272 nd	[12.52-12.92]	4 lanes +TWLTL	6 lanes (2 BAT), turn pockets, median (landscaping in design, 2005)
Kenmore SR 522				
Phase 1	60 th - 73 rd	[6.45 - 7.49]	5-7 lanes Varied with	6 lanes (2 BAT) turn pockets, median barrier, trees
Phase 2	73 rd -83 rd Pl	(7.49-8.23]	TWLTL & BAT lanes	6 lanes (2 BAT) turn pockets, median barrier, trees
Mukilteo SR 525				
Phase 1	Lincoln Way - 92 nd SW	[3.14 - 6.04]	2 lanes	4 lanes, turn pockets, median barrier, trees

Table 1-2. Type of Analysis and Project Timeline

	Limits	Project Dates	Data Collection	Study Type
SeaTac				
Phase 4	S 216 th -200 th	2004-2006	2001-2003 2007-2009	In-Service Evaluation Agreement Evaluate impacts of unshielded median trees
Phase 2	S 200 th -188 th	1997-1998	1994-1996 1999-2001	No In-Service Agreement because it was designed prior to the In-Service Agreement Evaluate impact of unshielded median trees
Phase 1	S 188 th -170 th	1996	1993-1995 1999-2001	No In-Service Agreement because it was designed prior to the In-Service Agreement Evaluate impact of unshielded median trees
Phase 3	S 170 th -152 nd	2002-2004	1999-2001 2005-2007	In-Service Evaluation Agreement Evaluate impacts of unshielded median trees
Federal Way				
Phase 1	S 324 th 312 th	2002-2003	1999-2001 2004-2006	In-Service Evaluation Agreement Evaluate impacts of unshielded median trees
Phase 2	S 340 th -324 th	2003-2004	2000-2002 2005-2007	In-Service Evaluation Agreement Evaluate impacts of unshielded median trees
Des Moines				
	SR-516-216 th	2003-2004	2000-2002 2005-2007	No In-Service Agreement needed because low-profile median barrier used Evaluate for comparison of median types
Kent				
Phase 1	S 272 nd -252 nd	2005-2006	2002-2004 2007-2009	No In-Service Agreement needed because no trees planted in median Evaluate for comparison of median types
Phase 2	S 252 nd -SR-516	2005-2006	2002-2004 2007-2009	No In-Service Agreement needed because no trees planted in median Evaluate for comparison of median types Pedestrian Crossing Study conducted
Shoreline				
Phase 1	N 145 th -165 th	2005-2006	2002-2004 2007-2009	In-Service Evaluation Agreement Evaluate impacts of unshielded median trees Pedestrian Crossing Study conducted
WSDOT- unincorporated King County				
	S 284 th -272 nd	2006-2007	2003-2005 2008-2010	No In-Service Agreement needed because no trees planted in median Evaluate for comparison of median types
Kenmore SR 522				
Phase 1	60 th - 73 rd	2007-2008	2004-2006 2009-2011	No In-Service Agreement needed because no trees planted in median Evaluate for comparison of median types
Phase 2	73 rd -83 rd Pl	2007-2008	2004-2006 2009-2011	No In-Service Agreement needed because no trees planted in median Evaluate for comparison of median types
Mukilteo SR 525				
	Lincoln Way - 92 nd SW	2003-2004	2000-2002 2005-2007	No In-Service Agreement needed because median trees planted behind barrier Evaluate for comparison of median types

Outcomes and Tradeoffs

Some of the benefits expected from the type of redevelopment proposed in these plans include reductions in turning movement conflicts from improved access control measures (median, driveway delineation and consolidation); capacity improvements from additional lanes and reduced access points; safety improvements for pedestrians and transit users; and smoothed traffic flow, with the potential for reductions in speeds due to the visual perception of a narrower roadway from the roadway delineation provided by the median and roadside trees.

On the other hand, some of these elements and effects may be viewed as presenting drawbacks. For example, although some stakeholders may view reduced speeds as a benefit to safety and livability, WSDOT views significant reductions in speeds as a drawback, given that one of its primary objectives is to design and operate highway facilities that function efficiently. Any reduction in speed may translate into reduced traffic flow, and thus a less efficient facility. Other drawbacks resulting from the streetscape redevelopment plans include potential increases in accidents at intersections; conflicts at concentrated locations such as mid-block left turn lanes; and the potential safety impacts of placing trees within the Design Clear Zone (DCZ). These potential impacts include an increase in the likelihood of severe injuries involving tree collisions, given the speed of the facility (40-45 mph); the effects that trees may have on pedestrian crossing behavior; and the impact the trees may have on drivers' sight distances. The maintenance of trees required to sustain the desired effects is also a consideration that must be addressed.

In brief, each of the included elements presents varying impacts that must be balanced to achieve a safe, efficient, and attractive facility that meets the needs of the varied stakeholders.

CHAPTER 2 DATA

DATA COLLECTION PLAN

The focus of the data collection plan listed in Table 2-1 is to capture the accident experience, traffic characteristics, and roadway and streetscape features along the projects in order to model the frequency and severity of accidents within each project before and after construction. The steps indicate the order in which the data were collected. Notes pertaining to these steps are listed below the table. They highlight some of the details that must be attended to for the data to be as accurate and complete as possible.

Table 2-1. Flowchart for Data Collection

Step 1: Obtain Landscape and Channelization Plan Sheets for:	
	<ul style="list-style-type: none"> • Project preceding current project • Current project
Step 2: Identify project limits and construction dates from plans and project documentation	
Step 3: Request accident records for 3-year periods:	
	<ul style="list-style-type: none"> • Prior to start of construction • Following completion
Step 4: Collect <i>before</i> and <i>after</i> data for:	
	<ul style="list-style-type: none"> • ADT • Speed Limits • Speed Studies
Step 5: Obtain maintenance records of median intrusions and tree incidents when available	
Step 6: Request alignment and curvature data	
Step 7: Obtain median, roadway, and roadside characteristics for 50-foot plan sheet sections	
Step 8: Verify geometric characteristics with video footage and/or site visits	
Step 9: Assimilate data components into two data structures	
	<ul style="list-style-type: none"> • Frequency structure based on accident counts for every 0.01-mile increment • Severity structure based on accident and roadway characteristics

Notes:

Steps 1 and 2: Obtain the plan sheets before requesting any other data. The plan sheets indicate the project limits more accurately than the general project definitions, which typically list the closest intersection. Whether or not the intersection is part of the redevelopment project is not

often specified in the summary project documentation, although including or excluding an intersection inappropriately will affect the modeling analysis and accident rates significantly.

Step 5: The In-Service Evaluation agreements stipulate that the cities will maintain and provide records to the investigators of any median intrusions, tree strikes, and tree replacements related to tree health within their project areas (both within medians and along sidewalks).

Steps 7 and 8: The plan sheets and video footage provide detailed information about the *before* and *after* roadway and roadside conditions. The *before* footage may provide the only accurate record of existing conditions, while the *after* video was used to verify the conditions specified on the plan sheets.

DATA COLLECTION EFFORTS

The data are being collected from numerous sources and compiled to provide the information needed for this analysis. Given that the purpose of this research is to quantify some of the safety tradeoffs made within the urban highway context, the data needs were initially defined to include accident experience, roadway geometries, traffic characteristics, level of access, and specific elements related to the median and roadside trees. General information, such as project limits and construction dates, was used to specify what data to collect.

Accident data were collected for the three years before project construction and are being collected for the three years after construction. This timeframe was selected on the basis of the time allotted to conduct the analysis. Similar research has shown that three years should be an adequate timeframe for accident analysis, reducing the likelihood that all of the data collected will be from years with non-typical accident occurrence. This phenomenon, termed regression to the mean, occurs because the chance of three consecutive years experiencing abnormal accident rates is much lower than the chance of one year being abnormal. It also ensures that any change captured is not due purely to the “novelty effect” of the new streetscape treatments. A longer timeframe could be used, but changing social conditions (e.g., land use, design features, demographics) could introduce changes in unmeasured variables, which could bias the results of the modeling. It is also less practical to conduct a study over a significantly longer timeframe, given the desire to analyze the data and apply the lessons learned.

The specific data collected are listed in Table 2-2. This table lists the general types of data collected, some of the variables specified for each type, and the sources of the data. The processes for obtaining each of these pieces of data are presented below.

Table 2-2. Catalog of Data Collection Efforts – Before and After

Data Categories and Sources	Examples of Specific Variables Collected
Catalog of roadway characteristics	
Collected from the As-Built Plans, State Highway Log, and video footage of highway	<ul style="list-style-type: none"> • Number of lanes • Widths • Vertical alignment
Curvature and alignment information from the WSDOT Transportation Data Office	<ul style="list-style-type: none"> • Horizontal curvature • Shoulders • Driveway presence • Lane uses (including TWLTLs) • Intersections • Median locations • Level of access control
Catalog of median and roadside features	
Collected from the As-Built Plans, State Highway Log, and video footage of highway	<ul style="list-style-type: none"> • Median widths • Left/U-turn pockets • Median and sidewalk tree counts and types • Sidewalk presence
Traffic characteristics	
From the WSDOT TDO, Annual Traffic Report, Speed Studies, and State Highway Log	<ul style="list-style-type: none"> • Average daily traffic • Speed limits • 85th percentile speeds (when available)
Accident experience	
From the WSDOT TDO collision records and the city maintenance office median intrusion and tree replacement reports	<ul style="list-style-type: none"> • State accident records • City maintenance records of median intrusions and tree replacement

Geometric Data

The State Highway Log (SHL) (WSDOT 1995 and 2004) was used to gather general information concerning the widths of the roadway, shoulders, and special-use lanes; the number of lanes in each direction; and some characteristics of the channelization approaching intersections. These data were verified in two ways, 1) by comparing the characteristics defined by the SHL to those observed on the As-Built Plans and 2) by observing the conditions before and after the project installation on the video log available through the WSDOT Transportation Data Office (TDO). Checking the data revealed discrepancies; in all cases the conditions observed in the video log were used in the data set.

The horizontal and vertical alignments were obtained from the WSDOT highway geometric database, specified for 1996 and 2002 to capture any effect of possible alignment changes during project construction. Horizontal curves were identified by the radius, degree of curvature, direction of curve (right or left), and length of curve. The vertical alignment was identified by the grade ahead and back, and by the length of curve.

As discussed in the literature review (Appendix A), the alignment of the highway is frequently a significant factor in predicting the frequency and severity of accidents. Thus it was important to include this information in the data set to determine whether it significantly contributes to the frequency or severity of accidents along SR 99.

Median and Roadside Data

Accurate and specific information related to the characteristics of the roadside, roadway, and median is important for the investigation to determine what elements, if any, are significant in predicting accident frequency or severity. In addition, as the In-Service Evaluation progresses, this information may provide valuable insights into the outcomes of differing median and roadside treatments. This may result in better-informed decisions for future projects, and may provide possible solutions in the event that mitigation of the effects of elements within existing treatments is warranted.

To obtain this information, the author used the Planting Plans (included in Appendix B) and As-Built Plans to identify individual elements along the entire project segments in 50-foot increments for SeaTac phases 1 and 2. The elements identified included, but were not limited to, the median width; tree count and type; the level of access control and presence of driveways in the increasing and decreasing directions; the presence and type of turn lane (including TWLTLs in the *before* conditions); intersection presence and signalization indicators; and roadside conditions, including the presence of sidewalks, count and type of trees, and bus stop locations in both the increasing and decreasing directions.

Conditions before project construction were determined from the As-Built Plans for the projects that preceded the current projects, which were constructed in the 1970s. The information was verified and corrected, as needed, by viewing video footage of the project sections recorded in 1993. This video footage helped in the identification of several significant differences between the As-Built Plans and existing conditions,

including one signal within SeaTac Phase 1 that was installed after the projects were constructed in the mid 1970s but before the current streetscape project. In addition, the video footage was used to identify the presence of bus stops and the type of access control existing through the corridor. Similarly, video footage recorded in 2003 for the SR View Web application (provided by the WSDOT TDO) was used to verify conditions indicated on the plans.

Traffic Characteristics

Data that capture traffic characteristics include traffic volumes, posted speed, and speed studies. Traffic volume data are being obtained from the WSDOT TDO and the Annual Traffic Report (WSDOT 2004). Gathering sufficient data to show variations in traffic flow along the highway sections within the analysis timeframe is important for the statistical modeling process. When sufficient data are not available for all years of the analysis, growth rates can be computed to extrapolate the available data. Use of as many average daily traffic (ADT) values as possible will increase the quality of these estimated data.

Posted speeds were obtained from the State Highway Log (WSDOT 1995 and 2004) and verified by using the SR View program online. When a discrepancy was noted for SeaTac, the project engineer provided documentation of a speed change following the completion of the streetscape projects. Any changes in speed limit must be recorded to analyze changes in driving behavior.

The results of mid-block speed studies were obtained from the WSDOT Northwest Region Traffic Office for sections where speed studies had already been conducted during *before* or *after* project conditions. Specific requests for additional speed studies were likewise processed through the WSDOT Northwest Region.

Accident Data

Accident data are being collected from WSDOT TDO records of all collisions reported to the Washington State Patrol. The information included in these records falls into four categories: 1) characteristics of the accident, such as location, direction, time, and type of collision; 2) environmental factors, such as weather and lighting conditions; 3) outcomes of the accident, including the number and severity of injuries and the types

of individuals involved in the collision (pedestrians, bicyclists, number of vehicles); and 4) characteristics of the first three vehicular drivers and the first two pedestrians or bicyclists. These factors include the individual's sobriety, restraint use in the vehicle, actions, and age. This detailed information will be used primarily in the accident severity modeling. However, it also provides opportunities for future investigation of specific outcomes, such as the frequency of rear-end accidents occurring in proximity to intersections, or the characteristics of pedestrian accidents before and after the construction of these projects.

Other Data Considerations

Because development along this corridor does not vary significantly from strip commercial development (particularly within the 2-mile SeaTac section in the current statistical models), this variable was not included in the analysis. If in the future this data set is used for additional analysis, including sections with different types of development, collection of this information may be worthwhile.

Data Set Compilation

These data sets have been compiled for accident frequency and severity modeling. The frequency data consist of individual accident counts by year for each 1/100 of a mile (approximately 50 feet), ADT values by year assigned to each 1/100 of a mile, and geometric information for the *before* and *after* conditions. The conditional severity data contain information for each collision occurring during the specified timeframe. This information includes an ADT value based on the year and location of each accident, geometric information similarly assigned on the basis of year and location, and the individual accident characteristics described above.

VARIABLE DESCRIPTIONS

Tables 2-3 and 2-4 present the variables available for the statistical modeling. The geometric data are being used for both accident frequency and severity modeling, whereas the accident-specific data are being used for the severity modeling and for the descriptive comparative analyses of the projects.

Table 2-3. Descriptions of Geometric Variables

Locator Variables	
ARM, SRMP	Location measured in 1/100 of a mile
North (increasing) and West (right side) South (decreasing) and East (left side)	
RoadW	Width of roadway including shoulders and turn lanes
WshldrW, EShldrW	Width of outside shoulder in each direction
Wdrvway, Edrvway	Individual driveway presence for each direction
BothDrv	Driveways on both sides
WAccess, EAccess	Type of access control for each direction
WSwalk, ESwalk	Presence of sidewalks in both directions
WTrees, ETrees	Count of trees for each 50-ft segment (~1/100 of a mile) in each direction
WType, EType	Type of sidewalk trees
WBus, EBus	Presence of a bus stop
NLanes, SLanes	Number of through lanes in each direction
NSULane, SSULane	Special use lane type for each direction
Median Conditions	
MedEnds	End of a median (typically at intersections)
MedW	Median width
MedTrees	Count of median trees for 50-ft segments (~1/100 of a mile)
MedTType	Type of median trees
LeftTL	Presence of a left turn lane
TLLoc	Location of left turn lane (approaching intersection or mid-block)
TLType	Type of left turn lane (TWLTL, left-in south, left-in north, left-out south)
Intersection Characteristics	
Intrscn	Presence of an intersection
Signal	Signal indicator
NumLegs	Number of legs at intersection
DDNAp, DDSAp, DDNDp, DDSdp	Distance from intersection to the nearest access point in the two approach and two departure directions
Curvature	
Hcvlength, Hcvangle	Horizontal alignment or curvature including the angle of curvature, the direction of the curve, and the curve length
CrvRight, CrvLeft	
Vclength, VGB, VGA	Vertical alignment or curvature data include the curve length and the grades ahead and back
Special Feature	
Special	Presence and type of special feature (pedestrian crosswalk, non-signalized intersection island)

Table 2-4. Descriptions of Accident and Traffic Variables

Accident Frequency	
Count1, Count2, Count3, TotalC	Annual counts for 1/100-mile segments, plus total count for three-year periods
ADT – Average Daily Traffic	
ADT1, ADT2, ADT3	Annual traffic flow for 1/100-mile segments
Accident Characteristics	
Yr, Mth, Day, Tm	Date and time of accident
DD1-DD8	Diagram data describing vehicle movements
Ctp1, Ctp2, Fobj1, Fobj2	Collision types and objects stuck
Inj,Ftl	The number of injuries and fatalities in each accident
Jct, Surf, OnOff, Wthr, Lit	Characteristics of the accidents, such as junction relationship, road surface, weather, and lighting
D1sx, D1ag, D1inj, D1rst, D1ejct, D1SOB, D1Ms1, D1Ms2, D1CC1, D1CC2	The characteristics of Driver 1, such as sex, age, sobriety, miscellaneous actions, and contributing circumstances – same for Driver 2 and Driver 3
V1spd, V1Sfs, V1actn1, V1actn2, V1TC, V1RT,	The characteristics of Vehicle 1, such as the posted speed, road surface type, actions, traffic control, and road type – same for Vehicle 2 and Vehicle 3
PB1sx, PB1ag, PB1stat, PB1Act, PB1SOB, PB1Cloth, PB1using, PBCC1, PB1CC2	The personal characteristics of the pedestrian or bicyclist, such as sex, age, sobriety, clothing color, actions, and contributing circumstances – same for the second pedestrian or bicyclist

CHAPTER 3 METHODOLOGY

The research for this project is occurring in two distinct quantitative forms: 1) the analytical process of comparing accident frequencies and severities and determining significant differences, and 2) the development of statistical models to explain the factors that contribute to the frequency or severity of accidents.

The initial analysis consists of a before/after comparison of the projects; evaluation of significant changes before and after project construction; and comparison to similar facilities statewide. This part of the analysis has been completed for the SeaTac Phase 1 and Phase 2 projects, while the *before* conditions are presented for all but two of the remaining sections. The *after* phase of the analysis which will allow for meaningful discussions pertaining to changes in the level of safety within each project area will be conducted in subsequent years, as specified in each project description. Comparisons are drawn between some of the project sections to highlight where there appear to be needs for safety improvements.

The statistical analysis consists of developing explanatory models that can compare the factors contributing to the frequency and severity of accidents before and after the project construction. As with the analysis noted above, this part of the safety analysis has been conducted for the SeaTac Phase 1 and 2 project areas.

In addition, SeaTac has supplied supplementary maintenance information about median intrusions and tree maintenance activities. The frequency of tree incidents offers qualitative insights into the potential future impacts of median and roadside trees once they have reached maturity (specifically once they have reached the 4-in. diameter that WSDOT specifies as a fixed object).

IN-SERVICE EVALUATION PROCESS

This research is structured as an in-service evaluation, which provides an opportunity for the parties involved to test the operational characteristics of streetscape designs in real-world conditions. This in-service evaluation will allow WSDOT to

analyze the effects of the streetscape redevelopment projects, including changes in user behavior and impacts to safety, and how the facilities operate.

A new clear zone standard for urban arterial sections could be developed through controlled testing or modeling of various median widths, tree sizes, and design features (e.g., berm height and slope). However, to do so would take a considerable amount of time. This delay could diminish the support that many redevelopment projects have worked hard to achieve with councils, businesses, communities, funding partners, and permitting agencies. The diminished support could jeopardize projects that are in their infancy, and projects that are farther along would likely have to rebuild support with some sectors, further delaying the date when project benefits would become reality. In contrast, the in-service evaluation process enables the projects to move forward expeditiously, with little impact to design documents, approvals already attained, funding secured, and political and community support developed.

ACCIDENT RATES

The WSDOT computes accident rates on the basis of the “exposure” of a roadway section. The exposure is based on the length of the section, the traffic volume along the section, and the duration of the analysis. Calculating accident rates in this way allows for comparisons between highway sections of different lengths and traffic volumes. The equations WSDOT uses in the *Washington State Highway Accident Report* (1996) for overall and fatal accident rates are presented below:¹

$$AccidentRate = \frac{(\#ofAccidents) \times (1Million)}{(SectionLength*) \times (AADT**) \times (365Days)} \quad \text{Equation 1}$$

$$FatalAccidentRate = \frac{(\#ofFatalAccidents) \times (100Million)}{(SectionLength*) \times (AADT**) \times (365Days)} \quad \text{Equation 2}$$

¹For these analyses, divide the rates by three, given the accident counts are for three years.

*If the section length is less than 1 mile, it is excluded from the formula.

**AADT = Annual Average Daily Traffic

A similar rate can be developed to quantify and compare the collision experience with fixed objects in each of the projects before and after the redevelopment. This rate is represented below:

$$FixedObjectCollisionRate = \frac{(\#ofFixedObjectAccidents) \times (10Million)}{(SectionLength^*) \times (AADT^{**}) \times (365Days^{\dagger})} \quad \text{Equation 3}$$

Overall accident rates, fatal accident rates, and fixed-object accident rates are calculated for each project section before and after the construction of the projects.

The *Washington State Highway Accident Report* (WSDOT 1996) lists statewide accident rates, as well as overall and fatal rates for each WSDOT region, county, and roadway classification. These rates are compared with those calculated for the project sections in this analysis, and changes in *before* and *after* conditions are noted.

REGRESSION MODEL SELECTION

To quantify any changes in accident frequency and severity, models were developed to specify which variables affect accident frequency and severity along the relevant sections of SR 99 before and after implementation of the streetscape redevelopment projects. The coefficients of the variables in the models will allow conclusions to be drawn regarding the level of impact, and any change in impact that the variables have on accident frequency or severity.

Accident Frequency Model

Count data, such as the frequency of accidents, can be modeled by using the Poisson or negative binomial (NB) models. These models are appropriate for modeling accident frequencies along a highway with varying characteristics (e.g., changes in traffic volumes, geometric conditions, levels or types of access) because they predict non-negative integer values that are drawn from a distribution approximating the occurrence of rare events (Washington et al. 2003, p. 241). The Poisson model is used when the variance within the data is approximately equal to the mean (i.e., $E[n_i] = \text{Var}[n_i]$). In

¹ For these analyses, divide the rates by three, given the accident counts are for three years.

accident frequency data this condition is often violated, typically with the variance being greater than the mean. In this case, the NB model may be more appropriate.

The general form of the Poisson model is defined by the following equation:

$$P(n_i) = \frac{\exp(-\lambda_i) \lambda_i^{n_i}}{n_i!} \quad \text{Equation 4}$$

where $P(n_i)$ is the probability of a highway section i having n_i accidents per year, and λ_i is called the Poisson parameter, which is equal to the expected number of accidents at highway section i , $E[n_i]$. To estimate the Poisson distribution it is necessary to specify the Poisson parameter, λ_i , as a function of explanatory variables. This is typically accomplished by using a log-linear relationship between the Poisson parameter and the explanatory variables:

$$\lambda_i = \exp(\beta X_i), \text{ or } \ln(\lambda_i) = \beta X_i \quad \text{Equation 5}$$

where X is the vector of explanatory variables and β is a vector of estimable parameters representing the magnitude and direction of influence that each variable has on the probable outcome (i.e., the frequency of accidents at the specified highway section). With this form of λ_i , the coefficient vector β can be estimated by standard maximum likelihood methods, with the likelihood function, $L(\beta)$, being

$$L(\beta) = \prod_i \frac{\exp(-\exp(\beta X_i)) \exp(\beta X_i)^{n_i}}{n_i!} \quad \text{Equation 6}$$

In turn, the log-likelihood function is more straightforward to manipulate:

$$LL(\beta) = \sum_{i=1}^n [-\exp(\beta X_i) + n_i \beta X_i - \ln(n_i!)] \quad \text{Equation 7}$$

As mentioned above, when the data mean is unequal to the variance, the Poisson model assumption of equality is violated. One of the primary reasons that the data mean may not equal the variance is that omitted variables may influence the β parameter

(Washington et al. 2003, p. 248). These missing variables can bias the coefficient estimates, resulting in erroneous inferences (Shankar et al. 1995). Therefore, to model data with unequal mean and variance, it is necessary to include an error term in the model. The negative binomial distribution includes a gamma-distributed error term and is thus appropriate for estimating data with unequal mean and variance. The negative binomial model, derived from the equation for the Poisson parameter above, is shown below:

$$\lambda_i = \exp(\beta X_i + \varepsilon_i), \text{ or } \ln(\lambda_i) = \beta X_i + \varepsilon_i \quad \text{Equation 8}$$

where ε_i is the gamma-distributed error term with mean 1 and variance α^2 . The addition of the ε_i term allows the mean to differ from the variance, as shown below:

$$\text{Var}[n_i] = E[n_i](1 + \alpha E[n_i]) \quad \text{Equation 9}$$

When α (the dispersion coefficient, typically called the overdispersion parameter) is not significantly different from zero, the negative binomial reduces to the Poisson distribution. When the mean is less than the variance ($\alpha < 1$), the data are underdispersed. In the case that $\alpha > 1$, the mean is greater than the variance and the data are overdispersed. Previous accident frequency modeling has shown that the occurrence of highway accidents is typically overdispersed (Milton and Mannering 1998; Sullivan 2004).

Under the negative binomial assumption, the distribution has the following form:

$$P(n_i) = \frac{\Gamma((1/\alpha) + n_i)}{\Gamma(1/\alpha)n_i!} \left(\frac{1/\alpha}{(1/\alpha) + \lambda_i} \right)^{1/\alpha} \left(\frac{\lambda_i}{(1/\alpha) + \lambda_i} \right)^{n_i} \quad \text{Equation 10}$$

where $\Gamma(\cdot)$ is the gamma function. Similar to the Poisson distribution, λ_i can be estimated by using the maximum likelihood estimate (MLE) method, based on the following likelihood function:

$$L(\lambda_i) = \prod_i \frac{\Gamma((1/\alpha) + n_i)}{\Gamma(1/\alpha) n_i!} \left(\frac{1/\alpha}{(1/\alpha) + \lambda_i} \right)^{1/\alpha} \left(\frac{\lambda_i}{(1/\alpha) + \lambda_i} \right)^{n_i} \quad \text{Equation 11}$$

where N is the total number of highway sections. This function is maximized by using the MLE method to obtain estimates for the β and α parameters.

To determine whether the data follow the Poisson or negative binomial distribution, a test for the significance of the dispersion coefficient, α , must be performed. One method commonly used to determine the significance of α is simply to run the negative binomial regression on the data and check the t-statistic of α . If the t-stat is insignificant (typically < 1.5 for the 95 percent confidence level), then the conclusion is that the Poisson distribution is appropriate.

Accident Injury Severity Model

Discrete outcome modeling investigates an inherently different type of phenomenon than frequency modeling. The discrete outcomes of a physical event such as a vehicular accident depend on numerous inputs, which may vary in significance from one type of outcome to another. For example, an accident can be classified as resulting in a severity level of property damage only (PDO), some type of injury, or possible injury. Each of these categories of severity may be influenced by different factors. The highest level of severity may result from accidents involving higher traveling speeds and vehicles traveling in opposite directions (such as head-on collisions). On the other hand, PDO accidents may involve slower speeds and rear end collisions. To improve the safety of a highway most efficiently, it is desirable to reduce the most severe injury accidents. It is also helpful to understand the relative probabilities of the various levels of accident severity in order to quantitatively compare the safety of the highway before and after a roadway construction project.

The discrete outcome model is based on probabilistic theory (Washington et al. 2003, p. 257), and takes on the form

$$P_n(i) = P(S_{in} \geq S_{in}) \forall I \neq i \quad \text{Equation 12}$$

with I denoting all possible severities for observation n , and S_{in} being the linear function of variables that determines for accident n the likely severity i , such that

$$S_{in} = \beta_i X_{in} + \varepsilon_{in} \quad \text{Equation 13}$$

The vector β_i is the estimable parameters for severity i , X_{in} is a vector of observable variables that influence the severity for accident n (e.g., geometric design, driver characteristics, traffic volume, environmental conditions), and ε_{in} is the disturbance term. This error term is included in the model estimation to accommodate for missing variables, the functional form of the equation (linearity may not be appropriate), and random variation in β , all of which may influence accident severity (Washington et al. 2003, p. 258).

Combining the two equations shown above results in the probability function for I discrete severity levels given n independent accidents:

$$P_n(i) = P(\beta_i X_n - \beta_I X_n \geq \varepsilon_{In} - \varepsilon_{in}) \forall I \neq i \quad \text{Equation 14}$$

By assuming a distribution of the random error term, ε , models can be developed that represent the probabilities associated with the different levels of accident injury severity.

If an extreme-value distribution is assumed for the error term ε , which has been termed the Gumbel distribution, the resulting multinomial logit (MNL) model can be estimated by using the maximum likelihood method.

Given the above distribution assumption, and rearranging terms from the equation shown above, results in the following general form of the MNL model:

$$P_n(i) = \frac{\exp[\beta_i X_{in}]}{\sum_{\forall I} \exp[\beta_I X_{In}]} \quad \text{Equation 15}$$

In turn, the log-likelihood function shown below can be used to estimate the parameter vectors, β_i , by the maximum likelihood method:

$$LL = \sum_{n=1}^N \left(\sum_{i=1}^I \delta_{in} \left[\beta_i X_{in} - \ln \sum_{\forall I} \exp(\beta_I X_{in}) \right] \right) \quad \text{Equation 16}$$

where δ_{in} is defined as being equal to 1 if the observed severity for accident n is severity level i and zero otherwise.

One concern with multinomial logit models is the presence of shared, unobserved characteristics between some severity levels. The model assumes that the error terms of the discrete outcomes are independent and identically distributed. Thus, there is a limiting assumption of the independence of irrelevant alternatives (IIA). In the case that unobserved characteristics are shared among some of the severity levels, the IIA assumption is violated. This will result in probabilities that are incorrect (Washington et al. 2003, p. 274). Several tests can be performed to determine whether significant shared, unobserved variables exist among severity levels. The Hassman and Small-Hsiao IIA tests produce a chi-square statistic that can be compared to the chi-square distribution. If it is significant, it is evidence of shared, unobserved variables, and remedial action must be taken.

Shankar et al. (1995), and Holdridge et al. (2005) have shown that grouping the accident severity levels into three categories (property damage only, injury, and possible injury) does not result in significant IIA issues. Their structure is used for this analysis, and the Hausman IIA test is performed to verify that the structure does not present any significant issues for this data set.

A likelihood-test ratio is used to determine how well a model fits the data. It is computed on the basis of the difference between the restricted log-likelihood (the coefficients of all independent variables are restricted to zero, with the exception of the constant) and the log-likelihood at convergence by using the following relationship:

$$\chi^2 = -2(LL(0) - LL(\beta)) \quad \text{Equation 17}$$

The value computed is χ^2 distributed and is compared to the critical χ^2 value for the degrees of freedom given for each model. When the calculated log-likelihood ratio is larger than the critical value, the model is concluded to be significantly better than a

constant at predicting the frequency of accidents. A more illuminating use of the log-likelihood ratio test is in comparing models with equal degrees of freedom. Models with higher χ^2 values are better, all else being equal. This test is used during the modeling to select between variables that are individually significant but insignificant when included in combination. This is particularly helpful in determining how to stratify some of the variables.

CHAPTER 4

RESULTS

The anticipated outcomes of this evaluation will quantify tradeoffs made within the urban context and support a qualitative understanding of the effects of several streetscape redevelopment elements. Of specific interest are the short- and long-term effects of street trees, including the frequency and severity of collisions with trees. Any difficulties with traffic maneuvers due to restricted access may also be illustrated. The end result of the analyses will support the development of new urban arterial median design standards.

We expect to identify whether the impacts of trees within urban arterial medians are a safety risk that WSDOT is prepared to accept within the conditions that exist along SR 99. If the results indicate that the safety impacts are unacceptable, then this study may result in additional analyses that help to identify what variables are most significant and whether there are conditions that, when specifically controlled, result in acceptable levels of risk.

The cities that entered into in-service agreements with WSDOT, and are thus part of the entire evaluation process, are Federal Way, SeaTac, and Shoreline. The cities of Des Moines, Kenmore, Kent, and Mukilteo, as well as an unincorporated section of SR 99, are also being evaluated for different parts of the analysis.

The cities that are implementing streetscape redevelopment plans are listed in Table 4-1. This table includes general accident and traffic characteristics, as well as each project's limits. In the following chapters, each project's development goals, objectives, and plan characteristics are discussed in the order of the project construction. As noted above, SeaTac was the first city to initiate this type of project along SR 99. Federal Way and Des Moines were next, followed by Kent, Shoreline, and the unincorporated section of SR 99. The projects along SR 522 and 525 in Kenmore and Mukilteo are included last. "Phases" within individual projects refer to separate projects that are typically constructed end-to-end with other phases within the same city or neighboring cities. Each phase is constructed independently but includes many of the same general features.

Because of widely divergent years of project implementation, this report currently presents the conditions of each section prior to redevelopment and the initial results from a few of the projects for which *after* data were available. Subsequent versions of this report will present later analyses and overall results.

Table 4-1. Traffic and Accident Characteristics Prior to Project Construction

City and Phase	Project Limits by Milepost	Median Conditions	AADT (*1000)	Accidents in 3 years	Accident Rate per MVM ¹
SeaTac					
Phase 4	[16.52-17.52]	TWLTL	26-28k	105	3.57
Phase 2	[17.53-18.35]	TWLTL	32-41k	146	3.63
Phase 1	[18.34-19.47]	TWLTL	30-45k	395	8.10
Phase 3	[19.48-20.66]	TWLTL	31-37k	266	6.37
Federal Way					
Phase 2	[8.65-9.68]	TWLTL ²	14-33k	213	6.85
Phase 1	[9.69-10.59]	TWLTL	22-32k	423	14.11
Des Moines					
	[15.49-16.51]	TWLTL	25-32k	237	6.70
Kent					
	[12.93-15.48]	TWLTL	24-29k	403	5.64
Shoreline					
	[40.47-41.48]	TWLTL	33-39k	337	7.55
WSDOT					
	[12.52-12.92]	TWLTL	NA	NA	NA
SR 522 Kenmore					
Phase 1	[6.45 - 7.49]	TWLTL through some sections	NA	NA	NA
Phase 2	[7.50-8.23]		NA	NA	NA
SR 525 Mukilteo					
	[3.14 - 6.04]	No median	14-34k	291	4.92

Table 4-2. Traffic and Accident Characteristics Following Project Construction

City and Phase	Project Limits by Milepost	Median Conditions	AADT (*1000)	Accidents in 3 years	Accident Rate per MVM
SeaTac					
Phase 2	[17.53-18.35]	TWLTL	27-45k	223	5.64
Phase 1	[18.34-19.47]	TWLTL	30-49k	341	6.86

¹ Per million vehicle miles traveled

² Two-Way Left-Turn Lane

CHAPTER 5

SEATAC REDEVELOPMENT

PROJECT DESCRIPTION

In the early 1990s, the City of SeaTac developed a comprehensive plan to redevelop International Boulevard, the section of SR 99 that runs through SeaTac. The city initiated discussions with WSDOT concerning the design characteristics it proposed to implement. In 1996 it constructed Phase 1 of its International Boulevard redevelopment plan, shown in Figure 5-1. The characteristics of this phase of the project included replacing the two-way left turn lane with a landscaped median, adding curbs and gutters throughout the project, consolidating and defining access points, undergrounding utilities, repaving, and adding sidewalks with street trees. Trees were planted throughout the median as well, including at locations in close proximity to intersections and along some narrow sections of the median next to left turn pockets.



Figure 5-1. SeaTac Phase 1 – Before and After Redevelopment

Between 1997 and 1998 SeaTac constructed Phase 2 of the International Boulevard plan, shown in Figure 5-2, with features similar to those in Phase 1.



Figure 5-2. SeaTac Phase 2 – Before and After Redevelopment

These first phases of the SR 99 redevelopment efforts received much recognition and have been viewed as the model for improvements along this urban corridor. SeaTac received an American Public Works Association award in 1997 for Phase 1 of this project and the 1999 Washington State "Project of the Year" award for Phase 2.

The city of SeaTac reported that by the end of 2000 (two to four years after completion of the first two phases of the project) it had replaced 64 median trees. These included several trees that were replaced up to four times. The maintenance records provided by the city indicated that approximately 90 percent of these replacements were necessary because a tree was hit by a vehicle, and the remaining 10 percent were due to the poor health of the tree.

Detailed maintenance reports provided by the city of SeaTac indicated that in 2002 and 2003 alone, vehicles struck at least 22 trees. The ten trees struck in medians were in medians that were between 4 and 5 feet wide. This width typically indicates that the median is close to an intersection. Of these incidents, only one was reported as a collision, and it involved two trees of 3-in. caliper within a 4-ft median approaching the intersection with S. 170th Street. Three trees were involved in another single incident, near the intersection with S. 192nd Street. The caliper of these trees ranged from 4 to 6 in. at 6 in. above the ground.

The twelve remaining trees listed in the maintenance/replacement reports were struck along the eastern sidewalk. The maintenance reports indicated that one accident took out three trees, and another took out four. Thus, a total of seven tree-related

incidents involved twelve trees. Tree caliper ranged from 2 to 5.5 in. at 6 in. above the ground. No Washington State Patrol collision reports were filed for the sidewalk incidents. The levels of access along the eastern and western sides of this section of SR 99 are markedly different: the east side provides multiple accesses to businesses, whereas access along the western side is very limited because it edges SeaTac International Airport. This difference may have contributed to the difference in the number of tree-strikes on the two roadsides.

It is interesting to note how few of the tree incidents were reported to the police as collisions. Two possible reasons for this are that 1) the incidents resulted in insignificant damage to the vehicles and occupants, or 2) those involved in the collisions decided that they did not want the police at the scene and therefore drove away without making any report. Figure 5-3 illustrates some of the damage incurred in one such median intrusion incident.



Figure 5-3. SeaTac Tree Strike within Landscaped Median

In addition, it is worth noting that additional trees were damaged by vehicles but not enough to necessitate replacing the tree, as illustrated in Figure 5-4. This is important because it indicates that not all incidents involving trees are significant. One can expect that even when the trees are larger, these types of incidents will not result in greater harm to the occupants, given that the impacts were so slight that the small trees were not knocked down.



Figure 5-4. SeaTac Tree Strike Not Necessitating Removal of Tree

After the installation of the initial phases and the experience with the median tree hits, WSDOT and SeaTac formalized the In-Service Evaluation agreement, under which SeaTac agrees to provide WSDOT information regarding accidents along these stretches of SR 99. This will allow both agencies to evaluate the impact of the redevelopment, particularly any impacts of placing street trees within the design clear zone. This agreement is intended to provide the data required by both agencies to independently evaluate the safety implications of this deviation from the current clear zone standards.

As SeaTac prepared to install phases 3 and 4, it evaluated the tree-strike and median intrusion occurrences and concluded that proximity to intersections and median width should be controlled to minimize future collisions with trees. As a result, the characteristics of phases 3 and 4 (Phase 3 was completed in 2004, and Phase 4 was under construction in 2005) changed to preclude planting trees in medians next to left-turn pockets or within the influence area of the intersection, as illustrated in Figure 5-5.



Figure 5-5. SeaTac Phases 2 and 3 – Comparison of Landscaping in Narrow Medians

The vegetation used in Phase 3 was substantially different from that used in phases 1 and 2, consisting of a greater variety of low-growing native plants and a varied selection of trees, as shown in Figure 5-6. Phase 4 will use vegetation similar to that used in Phase 3. The individual phases of the redevelopment plan are shown in Figure 5-7.

DATA ANALYSIS

Phase 1 Data Analysis

The roadway environment changed significantly during Phase 1 project construction, leading to expectations that the accident rate would also change. Controlled access would change where vehicles entered and egressed adjacent property, which was likely to change the locations of accidents. Different types of fixed objects would be in the roadside environment: *before* conditions included utility poles and other highway facility hardware, whereas after development, trees, luminaire poles, and signal hardware would be more prevalent.



Figure 5-6. SeaTac Phase 3 – Native Vegetation Used in Median

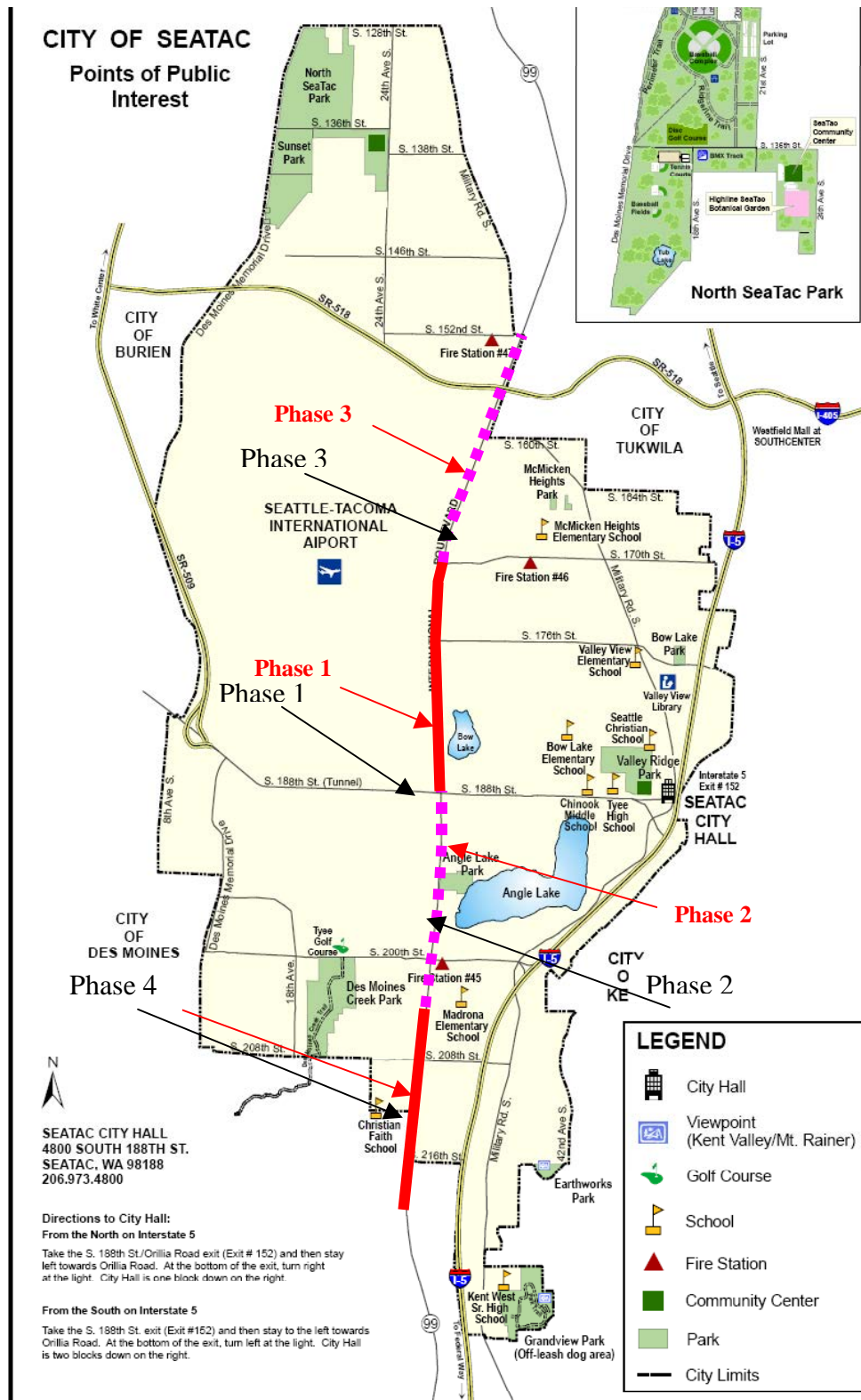


Figure 5-7. SeaTac – International Boulevard Streetscape Redevelopment Project Vicinity Map
(source: <http://www.ci.seatac.wa.us/localmaps/pointsofinterest.pdf>)

Accident Types

Prior to Phase 1 construction, the general accident characteristics for the 1.2-mile section included 395 accidents within three years (1993–1995). One was a fatal accident, and ten were pedestrian accidents (involving 11 pedestrians). One accident involved two pedestrians, both under the influence of alcohol, and 16 accidents involved drivers under the influence of alcohol.

After Phase 1 was completed, 341 accidents occurred between 1999 and 2001. Because Phase 1 was completed in 1996, data from 1997 through 1999 would have been preferred for analysis. However, because WSDOT had implemented a new accident record system, the data from 1997 and 1998 were not complete. Instead, the years following 1999 were used.

The general characteristics of these *after* accidents included one bicyclist accident, one accident involving two fatalities at the intersection with S. 188th Street, and seven accidents involving a total of eight pedestrians. Twenty-one accidents involved drivers who were under the influence of alcohol. Table 5-1 summarizes the *before* and *after* accident occurrences.

Table 5-1. SeaTac Phase 1 – Accident Characteristics Before and After Project Construction

	Total Accidents	Fatal	Bikes	Peds	DUI	
Before	395	1	4	10 ²	16	
After	341	1 ¹	1	7 ³	21	

3 years of data collected for before and after analyses

Section length = 1.20 miles

¹Two fatalities in one crash

²10 crashes involving 11 pedestrians

³Seven crashes, one involving two pedestrians

Before redevelopment, the accident categories that each accounted for approximately 10 percent or more of the total accidents included rear-end accidents (44 percent), driveway related (15 percent), sideswipes (14 percent), and left turns (11 percent). After the project was completed, the predominant accident categories included rear-ends (37 percent), left turns (24 percent), and sideswipes (12 percent). As noted above, the relative frequency of driveway related accidents reduced to 8.8 percent. Table 5-2 presents the predominant accident types before and after project construction. The

only type of accident that increased in frequency was the left turn accident. Following project construction, 76 of the 83 left turn accidents involved one vehicle going straight and the other turning left from the opposite direction. All of these were related to intersections, with one exception that was related to a driveway.

Table 5-2. SeaTac Phase 1 – Predominant Accident Types Occurring Before and After Project Construction

	Rear End	Driveway Related	Sideswipe	Left Turns	
Before	44%	15%	14%	11%	
After	37%	8%	12%	24%	

3 years of data collected for before and after analyses

Accident Rates

Prior to Phase 1 construction, traffic volumes within the study section ranged from approximately 30,000 to 45,000 vehicles per day (vpd), with an average of 37,100 vpd. WSDOT calculates overall accident rates with Equation 1, and fatal accident rates with Equation 2, as described in the Methodology section.

For SeaTac Phase 1 before the redevelopment, these calculations result in an overall accident rate of 8.10 accidents per million vehicle miles of travel (vmt), and a fatal accident rate of 2.06 per 100 million vmt (recognizing that there was only one fatal accident in the analysis timeframe). The 1996 statewide average accident rate for highway facilities classified as Urban Principle Arterials was 2.97 per million vmt, and the fatal accident rate was 1.02 per 100 million vmt. This section of SR 99 is within WSDOT's Northwest Region, and the average accident rate for all facilities in this region was 2.12 per million vmt (the fatal accident rate in WSDOT's Northwest Region was 0.73 per 100 million vmt). Likewise, within King County, the accident rate was 2.27 per million vmt, and the fatal accident rate was 0.58 per 100 million vmt. From this it can be concluded that both the overall and fatal accident rates along this section of SR 99 were higher than those on similarly classified statewide routes, within the WSDOT region, and within the county for the analysis timeframe.

Following the project's completion, the traffic volumes varied from 30,000 to 49,000 vehicles per day, with an average of 37,800 vpd. This resulted in an overall

accident rate of 6.86 accidents per million vmt and a fatal accident rate of 2.01 per 100 million vmt. From this it can be concluded that the accident rate improved, even though it was still significantly above the accident rate on similarly classified facilities.

Accident Locations

There are four major signalized intersections on this section of SR 99: S. 188th Street, an airport and hotel access, S. 176th Street (a T-intersection), and S. 170th Street. In addition, a minor signalized T-intersection provides access to office buildings on the east side of the highway. The individual accident occurrences of each of these intersections, both before and after the redevelopment, are summarized in tables 5-3 and 5-4. The intersection with the highest number of accidents was S. 188th Street, with 80 accidents within the three years prior to the project's construction. In total, before construction 65 percent of accidents were coded as related to intersections, whereas driveways accounted for 17 percent.

Table 5-3. SeaTac Phase 1 – Intersection and Driveway Accident Characteristics Before and After Project Construction

	Inter- sections	Drive- ways	Mid Block	188 th 18.35	184 th * 18.55	Airport & Hotel 18.76	Offices T-18.88	176 th T-19.10	170 th 19.47	
Before	5 ~65%	17%	18%	80	1	42	5	47	42	
After	6 ~78%	8.8%	13%	73	8	33	8	47	92	

3 years of data collected for before and after analyses

*The intersection with S. 184th Street was signalized during project construction

A pedestrian crossing signal was installed at MP 19.32 at the Denny's restaurant driveway

One new vehicular traffic signal was installed as part of Phase 1 at an existing, un-signalized intersection with S. 184th Street. After the project was finished, intersections experienced a higher percentage of the number of accidents along this section of highway, totaling 78 percent of the accidents in comparison to 65 percent before. This may have been due in part to the change in coding of accidents at the newly signalized location from “at driveway” to “at intersection,” particularly given that the percentage of “at driveway” accidents decreased. In general it could be expected that the accident rate at intersections might increase, given fewer mid-block left turn opportunities. In fact, the accident occurrences at the individual intersections varied considerably from one intersection to the next. At three of the major intersections, the

accident occurrences held constant or improved. S. 170th Street was the only intersection at which the accident rate significantly increased, more than doubling from 42 in three years to 92 in three years.

The left turn signal phasing at S. 170th Street was changed during the project from protected-only to protected/permissive. This resulted in an increase from two to 41 in left turn accidents involving traffic from the opposite direction. In addition, four of the six U-turning accidents involved traffic from the opposite direction; the other two involved right turning traffic. The S. 176th Street intersection, with protected/permissive phasing both before and after construction, also experienced a relatively large number of left turn accidents involving traffic from the opposite direction. The S. 188th Street and airport/hotel intersections had protected-only left turn phasing before and after construction.

Table 5-4. SeaTac Phase 1 – Signalized Intersection Accidents Before and After Project Construction

Accident Type	188 th 18.35		184 th 18.55		Airport /Hotel 18.76		Offices T-18.88		176 th T-19.10		170 th 19.47		Totals		
	B	A	B	A	B	A	B	A	B	A	B	A	B	A	
Before (B) or After (A)															
U-turning	0	0	0	1	0	2	0	0	0	1	0	6	0	10	
Left turn vs. opposite direction	7	6	0	2	2	4	1	1	25	19	2	41	37	73	
Rear End	43	30	0	3	24	18	3	5	11	15	19	21	100	92	
Sideswipe	12	12	1	1	9	4	0	0	3	2	3	4	28	23	
Enter at Angle	9	9	0	0	4	0	1	0	3	5	12	13	29	27	
Other	9	16	0	1	3	5	0	2	5	5	6	7	23	36	
Totals	80	73	1	8	42	33	5	8	47	47	42	92	217	261	

3 years of data collected for before and after analyses

Driveways changed from accounting for 17 percent of all accidents within the project to 8.8 percent. This change was likely associated with driveway consolidation and with fewer opportunities to access or egress driveways with left turn movements across the highway. The distribution of accidents along the highway before and after project construction illustrates that before construction, accident rates varied along the project section, whereas after construction, accident rates were more concentrated at intersections

and a few mid-block locations. Although accidents were more concentrated at intersections, given that only one major intersection had a worse accident rate, the landscaped medians do not appear to have negatively affected safety within this project area, and they may have actually smoothed traffic flow. Additional investigation into accident severities, presented below, sheds more light on the safety impacts of the landscaped medians.

Fixed-Object Collisions

The fixed-object collision characteristics within this section included 19 fixed-object accidents before and 13 after project construction. It is interesting to note that the number of objects struck decreased; to determine the significance of this decrease, it is helpful to look at the type of objects struck. The specific characteristics of the types of objects struck and the injury severity levels involved in fixed-object crashes are presented in Table 5-5.

After the project was completed, the types of objects struck and the frequency with which they were struck changed somewhat. Fewer curbs or medians were struck (three down from five), but there were four tree hits. All the tree-hit accidents resulted in property damage only. Two of the tree crashes occurred at intersections and involved drivers under the influence of alcohol. The other two were at mid-block locations.

The collision reports and diagrams were reviewed. The findings include that two of the accidents involved trees within the median, and the other two involved sidewalk trees. Three of the four collisions hit numerous trees. In three of them the damage to the vehicle was likely greater because of the presence of the trees. However, the vehicles that struck median trees might have traveled even farther across the opposing direction of travel had the trees not been there, exposing them to an even higher risk of colliding head-on with another vehicle. It is not possible to determine the severity of the outcome had the trees not been present. Trees blocking the visibility of the drivers does not appear to have been an issue.

Table 5-5. SeaTac Phase 1 – Fixed-Object Accident Characteristics Before and After Project Construction

	Before	After	
	19 crashes 20 fixed objects*	15 crashes 15 fixed objects	
Fixed Objects	<ul style="list-style-type: none"> • Utility pole (1) • Curb/traffic island (5) • Fence (2) • Luminaire pole (1) • Traffic signal pole (5) • Wood sign post (1) • Bridge rail face (1) • Roadway ditch (1) • Other object (3) 	<ul style="list-style-type: none"> • Tree or stump (4) • Curb/traffic island (4) • Fence (1) • Luminaire pole (1) • Traffic signal pole (1) • Wood sign post (1) • Retaining wall (1) • Rock bank or ledge (1) • Other object (1) 	
Severity of Fixed Obj Accidents	<ul style="list-style-type: none"> • Fatal (1) – rear-end + fence • Disable (3) – 1 traffic signal & 2 other objects • Evident Inj (3) • Possible Inj (3) • PDO (9) 	<ul style="list-style-type: none"> • Fatal (0) • Disable (0) • Evident Inj (1) • Possible Inj (1) • PDO (13) <p>All tree crashes resulted in property damage only</p>	
Maintenance Records	Not available	A total of 34 trees were replaced between 1999 and 2001, ~90% of them due to a vehicle strike	

*Note one crash involved two objects

Before project construction, 15 of the 19 fixed-object accidents resulted in accident severities ranging from property damage only to accidents with evident injuries. Three resulted in disabling injuries, and one accident resulted in a fatality. Two of the disabling injury accidents involved vehicles turning left at the intersection with S. 176th Street, and the other was entering a driveway. Each involved two vehicles. The fatal accident involved a mid-block, rear-end crash followed by one of the vehicles striking a fence. All of the fixed-object accidents after construction resulted in injuries at or below the evident-injury level, including the four tree hits, as noted above. It can be concluded that the landscaped medians did not have a negative impact on the frequency or severity of fixed-object crashes within this project area or analysis timeframe, and that the severity of all fixed-object accidents decreased within the analysis timeframe.

By using Equation 3, described previously, the fixed-object collision experience can be described in terms of a “fixed-object collision rate,” similar to the accident rate discussed above.

For SeaTac Phase 1 before redevelopment, this calculation results in a rate of 3.90 fixed-object collisions per 10 million vmt. This rate was similar to that of the other sections of SR 99 prior to redevelopment, which were frequently between 1.5 and 4 fixed-object collisions per 10 million vmt.

Following redevelopment, the fixed-object rate decreased to 3.38 collisions per 10 million vmt. This rate was still higher than that on any other section of SR 99, but considering the discussion of the injury severities above, it was definitely an improvement over the *before* conditions.

Injury Severity

The accident severities for all types of accidents are listed in Table 5-6. Disabling and fatal accidents accounted for 3.0 percent (12) of all accidents before the project, and 2.9 percent (10) after. The one fatal accident prior to project construction resulted from a rear-end crash followed by one vehicle striking a fence in the northbound direction, near a driveway (as noted above). In five of the eleven disabling injury accidents four pedestrians and one bicyclist sustained the disabling injuries. Three additional disabling injuries involved two-vehicle accidents at access points, in which the vehicles collided and then struck roadside fixed objects. The remaining accidents involved two or more vehicles crashing at access points.

Table 5-6. SeaTac Phase 1 – Injury Severities Before and After Project Construction

	Before	After	
Fatal	1	1	
Disabling Injury	11	9	
Evident Injury	41	49	
Possible Injury	125	88	
Property Damage Only	217	194	
Total	395	341	

Following project construction, the fatal accident resulted in two fatalities and a disabling injury in the “entering at angle” crash at the intersection with S. 188th Street. Prior to redevelopment the disabling injury accidents involved non-motorized users or fixed objects; after construction this was not the case. All but two of the accidents

resulting in disabling injuries involved two or more vehicles crashing at or near intersections. The exceptions included a pedestrian collision at the intersection with S. 176th Street and a vehicle that took evasive action and overturned.

The decrease in the number of disabling and fatal accidents was small, and the data were insufficient to test the statistical significance of this change. The authors conclude that the landscaped medians with trees less than 6 in. in diameter did not increase the number of the most severe or fatal accidents. Driveway-related injury accidents decreased from 28 to 16 following the project. Left turn versus opposite direction injury accidents at S. 170th Street increased from 0 to 22 after project completion. Additional analysis of the factors affecting injury severity may lead to conclusions regarding the changes in severity illustrated here. A chi-square test for the independence of the two injury-severity distributions presented in Table 5-6 indicated no statistically significant difference between the *before* and *after* values.

Pedestrian and Bicyclist Accidents

Of the all the accidents involving non-motorized users prior to project construction, only three occurred in direct relation to the major intersections along this stretch of highway (one at 188th and two at 182nd). However, at least four of these 14 accidents involved vehicle turning movements, indicating there are driveways or access points near these locations. Five of the non-motorized roadway users sustained disabling injuries, all in accidents occurring at mid-block locations.

Of the two bicyclist accidents that occurred after the project was completed, both related to access points. The injuries of the bicyclists were not severe. The decrease in the number and severity of accidents involving bicyclists is evidence that within the project area and analysis timeframe, the safety of bicyclists improved. However, the few accidents that occurred before and after the redevelopment are insufficient to develop statistical descriptors to quantify the level of improvement.

The number of accidents involving pedestrians also decreased during the analysis timeframe, from 10 beforehand to seven. The characteristics of these *after* accidents included four at the intersection with S. 188th Street and two at other intersections. In addition, one pedestrian accident occurred at the new, signalized pedestrian crosswalk near the mid-block left turn lane to Denny's restaurant, shown in Figure 5-8.



Figure 5-8. SeaTac Phase 1 – Signalized Pedestrian Crosswalk Near Denny’s Restaurant (Northbound and Southbound)

This accident occurred at 2:41 AM and involved two vehicles, one turning left and the other moving straight in the northbound direction. One of the drivers was under the influence of alcohol. In the image on the left in Figure 5-8, the mid-block left turn lane is just beyond the white car.

Speeds

No speed studies were conducted within Phase 1.

Phase 1 Summary

In summary, the number of accidents after construction decreased 14 percent, from 395 to 341. The locations of the accidents were more concentrated at intersections, although at most of the individual intersections the number of accidents decreased. The severity of fixed-object crashes was lower, and there was a general decrease in the severity of injuries in all accidents. The types of accidents that occurred most frequently changed, most notably an increase in left turn accidents and a decrease in rear-end accidents. Therefore, through 2001, the landscaped medians did not worsen accident occurrences within this project area and analysis timeframe, and by several measures the accident experience improved following the streetscape redevelopment project.

No speed studies were conducted within Phase 1 prior to the redevelopment project, so the effect of the streetscape redevelopment on travel speed cannot be gauged within this project area. However, the speed studies conducted after completion of this

project showed 85th percentile speeds ranging from 43 to 47 mph within the area with a 45 mph speed limit.

One lesson learned from this first phase of SeaTac's redevelopment efforts is that trees should not be placed close to intersections or left turn lanes. Within this project, such placement resulted in frequent tree hits, necessitating repeated tree replacement and eventual removal of trees.

Phase 2 Data Analysis

The roadway environment changed significantly during the Phase 2 project construction, leading to expectations that the accident experience would also change. Controlled access would change where vehicles entered and egressed adjacent property, which would likely change the locations of accidents. Different types of fixed objects would be in the roadside environment: *before* conditions included utility poles and other highway facility hardware, whereas after development, trees, luminaire poles, and signal hardware would be more prevalent.

Accident Types

Prior to Phase 2 construction, 146 accidents occurred along the 0.77-mile section from 1994 through 1996. This number includes three fatal accidents, eight pedestrian accidents (involving ten pedestrians), and one bicyclist accident. Two of the pedestrians were under the influence of alcohol, as were nine of the drivers. Of the three fatalities, two involved pedestrians. These accidents occurred at the intersection with S. 192nd Street. An additional fatal vehicular accident occurred at this intersection, and three additional non-fatal pedestrian accidents occurred near this intersection, including one that resulted in a disabling injury to the pedestrian.

After the project was constructed, 223 accidents occurred between 1999 and 2001. There were seven pedestrian accidents, one bicyclist accident, and zero fatalities. None of the pedestrians or bicyclists were under the influence of alcohol, although seven vehicular accidents involved drivers who were under the influence of alcohol. One bicyclist and two pedestrian accidents occurred at the intersection with S. 192nd Street, and three pedestrian accidents occurred at the intersection with S. 200th Street (resulting

in disabling injuries to two of the pedestrians). Table 5-7 summarizes the accident occurrences before and after project construction.

Table 5-7. SeaTac Phase 2 – Basic Accident Characteristics Before and After Project Construction

	Total Accidents	Fatal	Bikes	Peds	DUI	
Before	146	3	2	8 ¹	9	
After	223	0	1	7	7	

3 years of data collected for before and after analyses

Section length = 0.77 miles

¹Two crashes each involved two pedestrians (total 10)

The accident categories that each accounted for approximately 10 percent or more of the total *before* accidents included rear-end accidents (34 percent), driveway related (25 percent), and entering at angle (11 percent). The predominant accident categories after the construction included rear-end accidents (26 percent), sideswipes (10 percent), and left turn accidents (40 percent). Table 5-8 lists this information for the *before* and *after* conditions.

Table 5-8. SeaTac Phase 2 – Predominant Accident Types Occurring Before and After Project Construction

	Rear End	Driveway Related	Sideswipe	Left Turns	Enter at Angle	
Before	34%	25%	8%	3%	11%	
After	26%	4%	10%	40%	6%	

The most notable changes were the increase in the percentage of left turn accidents and the decrease in driveway-related accidents. The 85 of the 88 left turn accidents occurred at the three intersections in the *after* conditions. Before the project, these intersections experienced a variety of accident types, including rear-ends, sideswipes, and entering at angle accidents. In addition to differing types of accidents, these intersections also experienced fewer accidents. Therefore, the increase in left turn accidents can be attributed to the changing movements at the intersections. The reduction in driveway-related accidents can be attributed to the increase in access control. The median prevents vehicles from making left turns to or from driveways, thus reducing the

number of conflicting movements at these locations. There were also fewer access points, as driveways were consolidated.

Accident Rates

The traffic volumes within the project section between 1994 and 1996 ranged from 32,000 to 41,000, averaging 36,700 vehicles per day. The overall accident rate for Phase 2 calculated with Equation 1 equals 3.63 accidents per million vmt. The fatal accident rate (calculated with Equation 2) is 7.47 per 100 million vmt. As noted in the discussion of Phase 1, these rates exceeded those of similarly classified facilities in Washington State, as well as the average accident rates in King County and the Northwest Region in 1996. However, the overall Phase 2 accident rate was significantly lower than that of Phase 1, which equaled 8.10 per million vmt. This may have been due, in part, to the difference in the number of intersections in these projects. There were six intersections within the Phase 1 section of SR 99 but only three intersections within the Phase 2 section. However, the Phase 2 fatal accident rate was higher than that of Phase 1, and given that two of the fatalities were pedestrians (unlike in Phase 1), an independent analysis of the safety of non-motorized users may be appropriate.

Following the completion of Phase 2, the accident rates from 1999 to 2001 were based on traffic volumes that varied between 27,000 and 45,000 along the project section, averaging 36,100 vpd. The accident rate rose to 5.64 per million vmt. However, the fatal accident rate dropped to zero.

Accident Locations

There were two major intersections within the project area: S. 200th and S. 192nd streets. Overall, prior to the project 46 percent of the accidents within the project section were related to intersections, while 24 percent were related to driveways. S. 192nd Street experienced 24 accidents, and S. 200th Street experienced 47 before project construction. The severity of accidents at S. 192nd was relatively high, given that all of the fatalities occurred there. The *before* and *after* accident characteristics of the project and intersections are presented in tables 5-9 and 5-10.

Table 5-9. SeaTac Phase 2 – Intersection and Driveway Accident Characteristics Before and After Project Construction

	Intersections	Driveways	Mid Block	200 th 17.52	195 th * 17.86	192 nd 18.10	
Before	2 ~ 45.9%	24.0%	30.1%	47	9	24	
After	3 ~ 82.5%	4.5%	13.0%	111	35	38	

3 years of data collected for before and after analyses

*The intersection with S. 195th Street was signalized during project construction

Table 5-10. SeaTac Phase 2 – Intersection and Driveway Accident Characteristics Before and After Project Construction

Accident Type	200 th 17.52		195 th 17.86		192 nd 18.10		Totals	
Before (B) or After (A)	B	A	B	A	B	A	B	A
U-turning	0	4	0	7	0	3	0	13
Left turn vs. opposite direction	3	49	0	16	2	17	5	68
Rear End	20	27	3	7	2	5	25	38
Sideswipe	4	7	1	1	2	3	7	11
Enter at Angle	5	10	0	0	10	1	15	11
Other	16	14	3	4	7	9	20	22
Totals	48	111	7	35	23	38	72	184

3 years of data collected for before and after analyses

A third intersection was signalized during the project, at S. 195th Street. Nine accidents occurred at this location prior to signal installation; this number increased to 35 after the signal was installed. However, the number of accidents between signalized intersections decreased after the project was constructed. This was presumably due to fewer opportunities to turn left mid-block because of the median, which forces those wanting to turn left to drive to the intersections for U-turn movements.

Following completion of the project, 83 percent of the accidents were related to intersections, and 5 percent were related to driveways within the project area. Part of the increase in the percentage of accidents related to intersections was due to the new signalized intersections. Before the signal at 195th was installed, accidents at this location were coded as being “at a driveway” or not related to an intersection. After the signal installation, the coding changed to reflect the signal presence, with most accidents coded

as “at an intersection.” As noted above, the accident rate at each of the signalized intersections also increased.

The left turn signal phasing at S. 200th Street was changed during the project from protected-only to protected/permissive. This resulted in an increase from three to 49 in left turn accidents involving traffic from the opposite direction. In addition, three of the four U-turning accidents involved traffic from the opposite direction. The S. 200th Street left turn phasing was changed back to protected-only during the SeaTac Stage 3 project. The S. 195th Street and S. 192nd Street signals, installed with protected/permissive left turn phasing, also experienced large increases in the number of left turn accidents involving traffic from the opposite direction.

Fixed-Object Collisions

Additional accident characteristics within this section included ten fixed-object accidents before Phase 2 was constructed. Seven were listed as the primary accident type and three as the secondary accident type. The objects struck are listed in Table 5-11. The severity of fixed-object accidents before project construction ranged from property damage only to one that was a disabling injury. The disabling injury accident was at a mid-block location and involved one vehicle that struck a building, injuring two of the occupants. The driver was under the influence of alcohol.

After construction was completed, eleven fixed-object accidents occurred, all listed as the primary accident type. The types of objects struck are also listed in Table 5-11. Of particular interest are the four trees and five curbs or medians that were struck following the median installation. The severity of these *after* fixed-object accidents ranged from property damage only to one disabling injury. This disabling injury accident occurred at a mid-block median left turn pocket (allowing both left-in and left-out movements across SR 99). One vehicle struck a curb, median, or traffic island. The other “curb, median, or traffic island” crashes did not result in any injuries.

The collision reports and diagrams for the accidents involving trees were evaluated. The findings include the following:

- Two involved the narrow median near the S. 192nd Street intersection.

- The accident that resulted in an injury to the driver of vehicle 2 resulted when vehicle 1 failed to yield the right-of-way, and vehicle 2 swerved into the median.
- The sidewalk tree incidents resulted when the vehicles swerved while turning right onto SR 99, striking trees on the sidewalk near the driveways they were exiting.

Table 5-11. SeaTac Phase 2 – Fixed-Object Accident Characteristics Before and After Project Construction

	Before	After	
	13 crashes 15 fixed objects*	16 crashes 16 fixed objects	
Fixed Objects	<ul style="list-style-type: none"> • Curb/traffic island (1) • Fence (1) • Utility pole (1) • Luminaire pole (1) • Wood sign post (2) • Traffic signal (1) • Boulder (2) • Other object (3) • Roadway ditch (1) • Building (1) • Temporary traffic sign or barricade (1) 	<ul style="list-style-type: none"> • Curb/traffic island (5) • Fence (1) • Utility pole (1) • Metal sign post (1) • Tree or stump (4) • Retaining wall (1) • Construction machinery (1) • Other object (2) 	
Severity of Fixed Obj Accidents	<ul style="list-style-type: none"> • Fatal (0) • Disable (1) - building • Evident Inj (3) • Possible Inj (1) • PDO (8) 	<ul style="list-style-type: none"> • Fatal (0) • Disable (1) - curb • Evident Inj (1) • Possible Inj (0) • PDO (14) <p>Tree crashes resulted in 3 PDO and 1 evident injury</p>	
Maintenance Reports	Not available	Four median trees were replaced during the 1999-2001 analysis time frame	

*Note two crashes each involved two objects

Of the two median tree collisions, one involved three trees. Therefore, of the four maintenance records, three of them relate to this one accident.

The conclusions from evaluating the diagrams of these accidents are that two of the accidents may not have been reported as accidents had the trees not been present. The accident resulting in an injury was related more to the presence of the median than the tree, given that the tree sustained minimal damage. In addition, one of the collisions with a sidewalk tree also involved a light pole, and thus most probably it would have been reported as an accident even without the tree.

The fixed-object collision rate can be calculated with Equation 3, described previously. For SeaTac Phase 2 before the redevelopment, this calculation results in a rate of 3.23 fixed-object collisions per 10 million vmt. This rate is similar to those of the other sections of SR 99 prior to redevelopment, which were frequently between 1.5 and 4 fixed-object collisions per 10 million vmt, and it is lower than that of the Phase 1 project area.

Following redevelopment, the fixed-object rate increased to 5.48 collisions per 10 million vmt. This rate is higher than the other section of SR 99, exceeding the Phase 1 *before* rate of 3.90. However, given the discussion of injury severities above, most of the increase in the frequency of fixed-object collisions was associated with no physical injury to those involved.

Injury Severity

Table 5-12 lists the frequency of injuries at each severity level for the *before* and *after* conditions. Although the number of accidents at most of the injury levels increased, this was due to the overall increase in the frequency of accidents. There does not appear to have been a disproportionate increase in injury levels in comparison to property-damage accidents. In fact, the severity of accidents appears to have been relatively constant, with the exception of the reduced frequency of fatal or disabling injuries, which changed from 7.1 percent (7) to 2.7 percent (3). With the small of a number of accidents in this category, it is difficult to test the statistical significance of this change. However, it is encouraging to see that the frequency of the highest severity accidents decreased over the study period.

Table 5-12. SeaTac Phase 2 – Injury Severities Before and After Project Construction

	Before	After	
Fatal	3	0	
Disabling Injury	7	7	
Evident Injury	20	42	
Possible Injury	39	60	
Property Damage Only	77	114	
Total	146	223	

Pedestrian and Bicyclist Accidents

Prior to the construction of the Phase 2 project, eight pedestrian accidents (involving ten pedestrians) and two bicyclist accidents occurred. Two of the pedestrians were under the influence of alcohol. The severity of these accidents was high: the three fatalities within the Phase 2 project area involved two of the pedestrians and a vehicular driver, and they all occurred at the intersection with S. 192nd Street. In addition, three non-fatal pedestrian accidents occurred near this intersection.

Following the Phase 2 project construction, the bicyclist accident occurrence decreased to one accident, and the number of pedestrian-related accidents decreased from eight to seven. Following redevelopment, the bicyclist accident and two pedestrian accidents occurred at the intersection with S. 192nd Street, three pedestrian accidents occurred at the intersection with S. 200th Street (resulting in disabling injuries to two of the pedestrians), and one disabling injury accident occurred at the intersection with S. 195th Street.

The frequency and severity of pedestrian and bicyclist accidents at the intersection with 192nd Street did not increased following construction, although with the low magnitude of the changes, it is impractical to determine the statistical significance of these changes. The safety of pedestrians may have improved, as the number of accidents changed from eight accidents with two fatalities, to seven accidents resulting in three disabling injuries.

Speeds

No speed studies were performed for Phase 2.

Phase 2 Summary

To summarize, the number of accidents increased by 53 percent, from 146 to 223, and the locations and characteristics of the accidents shifted. The number of rear end, driveway and entering at angle accidents decreased, and sideswipes and left turn accidents increased. Similar to Phase 1, there were fewer of the most severe injury accident types. The number of fixed-object crashes increased, but they exhibited decreasing injury severity levels. Four trees were struck after the project was installed, resulting in only one accident with any evident injury. The overall accident rate increased

following the construction of the Phase 2 project, although the bicyclist and pedestrian accident experience improved (as in Phase 1).

As in Phase 1, no speed studies were conducted prior to the redevelopment project. However, the speed studies conducted following completion of this project showed 85th percentile speeds ranging from 41 to 47 mph within the area with a 45 mph speed limit. This speed range is similar to the speeds that were recorded in Phase 1.

As noted above, the tree-strike and replacement experience following the completion of phases 1 and 2 resulted in revisions to the landscaping plans that precluded planting trees in narrow medians or within the influence area of intersections. These revisions were put into effect for phases 3 and 4.

Phase 3 Data Analysis

As with phases 1 and 2, the roadway environment changed significantly during the Phase 3 project construction, leading to expectations that the accident occurrence will also change. Controlled access will change where vehicles enter and egress adjacent property, which will likely change the locations of accidents. Different types of fixed objects will be in the roadside environment: *before* conditions included utility poles and other highway facility hardware, whereas after development, trees, luminaire poles, and signal hardware will be more prevalent. This analysis presents the *before* conditions only because construction of the project was completed in 2004, and therefore, three years of data are not yet available for the comparative analysis.

Accident Types

Between 1999 and 2001, before Phase 3 of the International Boulevard project was constructed, 266 accidents occurred within the 1.19-mile section. The accidents (summarized in Table 5-13) included two bicyclist accidents and four pedestrian accidents involving five pedestrians. Three of the pedestrians were under the influence of alcohol, and two of them sustained disabling injuries. Seventeen drivers were under the influence of alcohol, including one involved in a crash with a bicyclist.

Table 5-13. SeaTac Phase 3 – Accident Characteristics Before Project Construction

	Total Accidents	Fatal	Bikes	Peds	DUI	
Before	266	0	2	4 ¹	17	
After*						

3 years of data collected for *before* analysis

Section length = 1.19 miles

**After* data for 2004-2006 will be available in 2007

¹Involving five pedestrians

The types of accidents that represented roughly 10 percent or more of accidents experienced within the project area prior to construction are listed in Table 5-14 and include rear-end (51 percent), sideswipe (9 percent), and left turns (14 percent). These types of accidents are comparable with those from the first two phases of the International Boulevard redevelopment project, although the rear-end accident rate was higher than the 44 percent and 30 percent within phases 1 and 2, respectively.

Table 5-14. SeaTac Phase 3 – Predominant Accident Types Occurring Before Project Construction

	Rear End	Sideswipe	Left Turns	Enter at Angle	
Before	51%	9%	11%	14%	
After*					

3 years of data collected for before and after analyses

**After* data for 2004-2006 will be available in 2007

Accident Rates

Prior to project construction, the traffic volume along SeaTac's Phase 3 section varied between approximately 31,000 and 37,000 vehicles per day, with an average volume of 32,100 vpd. WSDOT calculates accident rates on the basis of traffic volumes and accident experience by using Equation 1, described previously.

For SeaTac Phase 3 before redevelopment, this calculation results in an overall accident rate of 6.37 accidents per million vmt. Given that there were no fatal accidents within the analysis timeframe, the fatal accident rate was zero. The statewide average accident rate for highway facilities classified as Urban Principle Arterials was 2.97 for 1996. This section of SR 99 is within WSDOT's Northwest Region, and the average

accident rate for all facilities in this region was 2.12 per million vmt. Likewise, within King County, the accident rate was 2.27 per million vmt. From this it can be concluded that the overall accident rate along this section of SR 99 was higher than that on similarly classified routes and than rates within the WSDOT region and county for the analysis timeframe. In comparison to other sections of SR 99 within this analysis and prior to any redevelopment projects, SeaTac's Phase 3 accident rate was one of the highest.

Accident Locations

Within the Phase 3 project area prior to the construction of the project, 86 percent of the accidents related to intersections, while the remaining 14 percent related to driveways and non-access points within the mid-block sections (Table 5-15). There were five signalized intersections, and one signal was added at an existing, unsignalized T-intersection with a driveway. The intersections with S. 160th and S. 154th experienced the highest number of accidents, with 69 and 53 occurring at each, respectively, within the 3-year analysis timeframe.

Three years of *after*-project data will be available in 2007.

Table 5-15. SeaTac Phase 3 – Intersection and Driveway Accident Characteristics Before Project Construction

	Inter- sections	Drive- ways	Mid Block	167 th 19.64	New [#] 19.79	160 th 20.12	SR 518 ramp 20.37	154 th 20.52	152 nd 20.66	
Before	5 ~ 86%	12%	1.9%	5	4	69	11	53	35	
After*	6									

3 years of data collected for the *before* analysis

[#]A new signal (T-intersection) is being installed at MP 19.79

**After* data for 2004-2006 will be available in 2007

Fixed-Object Collisions

Within Phase 3, six fixed-object accidents occurred before construction began. The objects struck are listed in Table 5-16. The one injury sustained by an individual in these fixed-object crashes occurred when a vehicle was traveling in the southbound direction approaching the intersection with S. 170th Street. It crossed all lanes of traffic and struck a tree on the east sidewalk at 12:54 AM. The remaining five accidents did not result in any injuries.

Table 5-16. SeaTac Phase 3 – Fixed-Object Accident Characteristics Before Project Construction

	Before	After*
	6 crashes 6 fixed objects	X crashes X fixed objects
Fixed Objects	<ul style="list-style-type: none"> • Building (1) • Construction machinery (1) • Fence (2) • Roadway ditch (1) • Tree or stump (1) 	<ul style="list-style-type: none"> •
Severity of Fixed-Object Accidents	<ul style="list-style-type: none"> • Fatal (0) • Disable (0) • Evident Inj (1) – tree • Possible Inj (0) • PDO (5) <p>Tree crash resulted in evident injury</p>	<ul style="list-style-type: none"> • Fatal () • Disable () • Evident Inj () • Possible Inj () • PDO ()

*After data for 2004-2006 will be available in 2007

There were no fatalities, but five disabling injuries accounted for 2 percent of the accidents. Thus, the initial rate of the highest severity injuries was lower than those for phases 1 and 2, which initially experienced 3 percent and 7 percent of fatal or disabling injury accidents, respectively. Table 5-17 lists the frequencies of each injury level.

Fixed-object collisions can be described in terms of a “fixed-object collision rate,” similar to the accident rate described above, by using Equation 3. For SeaTac Phase 3 before redevelopment, this calculation results in a rate of 1.44 fixed-object collisions per 10 million vmt. This rate is lower than those of the other sections of SR 99 prior to redevelopment, which were frequently between 1.5 and 4 fixed-object collisions per 10 million vmt.

Injury Severity

The disabling injury accident experience accounted for 1.9 percent of all accidents. This is lower than the statewide average of 3.0 percent and the Northwest Region average of 2.3 percent.

Table 5-17. SeaTac Phase 3 – Injury Severities Before Project Construction

	Before	After*	
Fatal	0		
Disabling Injury	5		
Evident Injury	30		
Possible Injury	80		
Property Damage Only	151		
Total	266		

After data for 2004-2006 will be available in 2007

Pedestrian and Bicyclist Accidents

Prior to construction of the Phase 3 project four pedestrian accidents involved five pedestrians. Three of the pedestrians were under the influence of alcohol, and two of them sustained disabling injuries when crossing the road at the intersection with S. 167th Street. The remaining three pedestrians were struck at intersections or driveways as well. Two bicyclists were struck at or near the intersection with S. 160th Street. One of the drivers in these accidents was under the influence of alcohol.

Speeds

Spot speed studies were conducted in 2000 at mid-block locations prior to and following the project's construction (at mileposts 19.77 and 19.63, respectively). The 85th percentile speeds in these studies ranged from 46 to 48 mph. Following completion of the project, spot speed studies recorded 85th percentile speeds ranging from 43 to 47 mph in 2005, indicating a marginal reduction in average speeds within the project area. However, the speed limit of 45 mph changed to 40 mph between S. 152nd and S. 200th streets on February 19, 2003. Therefore, although travel speeds reduced, there is evidence that a higher percentage of vehicles exceeded the posted speed.

Phase 3 Summary

Spot speed studies indicated that the average speeds of motorized travelers on SR 99 within Phase 3 decreased following the completion of construction. However, given that the posted speed limit changed from 45 to 40 mph during construction, the speed

studies also indicated that after construction, a higher percentage of travelers exceeded the speed limit than before.

Phase 4 Data Analysis

The roadway environment will change significantly during Phase 4 project construction, leading to expectations that the accident experience will also change. Controlled access will change where vehicles enter and egress adjacent property, which is likely to change the locations of accidents. Different types of fixed objects will be in the roadside environment: *before* conditions included utility poles and other highway facility hardware, whereas after development, trees, luminaire poles, and signal hardware will be more prevalent. This analysis presents the *before* conditions; the *after* data for the Phase 4 comparative analysis will be available in 2009.

Accident Types

Before Phase 4 of the SeaTac International Boulevard redevelopment project, 105 accidents occurred within three years over the 0.99-mile segment. The accidents (summarized in Table 5-18) included one fatal pedestrian accident, three additional accidents involving pedestrians, and one bicyclist accident. Seven of the drivers were under the influence of alcohol.

Table 5-18. SeaTac Phase 4 – Accident Characteristics Before Project Construction

	Total Accidents	Fatal	Bikes	Peds	DUI	
Before	105	1	1	4	7	
After*						

3 years of data collected for before and after analyses

Section length = 0.99 mile

**After* data for 2006-2008 will be available in 2009

The predominant accident types listed in Table 5-19 accounted for more than 10 percent of the accidents within the project area. They are rear-end accidents (34 percent), driveway related (26 percent), and entering at angle (16 percent). These accident types are similar to those that were most frequent in the earlier phases of the International Boulevard project.

Table 5-19. SeaTac Phase 4 – Predominant Accident Types Occurring Before Project Construction

	Rear End	Driveway	Enter at Angle	
Before	34.3%	25.7%	16.2%	
After*				

3 years of data collected for before analysis

*After data for 2006-2008 will be available in 2009

Accident Rates

Prior to project construction, traffic volumes along the Phase 4 section of SR 99 varied between approximately 26,000 and 28,000 vehicles per day, with an average volume of 26,900 vpd. WSDOT calculates accident rates on the basis of traffic volumes and accident experience by using Equation 1.

For SeaTac Phase 4 before redevelopment, this calculation results in an overall accident rate of 3.57 accidents per million vmt. The fatal accident rate is calculated with Equation 2, and it equals 3.43 fatal accidents per 100 million vmt. The 1996 statewide average accident rate for highway facilities classified as Urban Principle Arterials was 2.97 per million vmt, and the fatal accident rate was 1.02 per 100 million vmt. This section of SR 99 is within WSDOT's Northwest Region, and the average accident rate for all facilities in this region was 2.12 per million vmt (the fatal accident rate in the Northwest Region was 0.73 per 100 million vmt). Likewise, within King County, the accident rate was 2.27 per million vmt, and the fatal accident rate was 0.58 per 100 million vmt. From this it can be concluded that both the overall accident rate and the fatal accident rate along this section of SR 99 were higher than those on similarly classified routes and within the WSDOT region and county for the analysis timeframe.

The fatal accident rate for SeaTac Phase 4 was higher than those of the other sections of SR 99 in this analysis. However, this rate is based on only one fatal accident within the three-year analysis period.

Accident Locations

One intersection is within the limits of this project, which extends from just north of S. 216th Street (Des Moines made improvements to this intersection) to south of S.

200th Street, which was part of the Phase 2 improvements. In Phase 2 the channelization south of the intersection with S. 200th Street included a narrow median with trees planted along the left turn lane in the northbound direction. Consistent with the Phase 1 conclusions regarding the placement of trees within narrow medians close to intersections, these trees were removed in 2005 in preparation for installing the Phase 4 improvements; other vegetation or rockery will be used to replace them.

Of the accidents occurring within the project area, 53 percent were related to intersections. Twenty-six accidents occurred at the existing intersection, S. 208th Street. A new signal is planned for the intersection with S. 204th Street; prior to this signal being installed this intersection experienced 20 accidents. This information is summarized in Table 5-20. The number of accidents experienced at each of these intersections was lower than that at most other major signalized intersections within SeaTac, which ranged from 35 to 92 accidents within three years. However, minor intersections experienced as few as five accidents within three years. This may reflect the traffic volumes on both the side streets and SR 99 at these locations.

Table 5-20. SeaTac Phase 4 – Intersection and Driveway Accident Characteristics Before Project Construction

	Total Intersections	Total at Driveways	Mid Block	208 th 17.02	204 th # 17.27	
Before	1 ~ 53.3%	22.9%	22.9%	26	20	
After*	2					

3 years of data collected for before analysis

#New traffic signal installed at S. 204th Street

*After data for 2006-2008 will be available in 2009

Fixed-Object Collisions

Additional accident characteristics of note include fixed-object crashes. Within the three-year timeframe, eight crashes involved fixed objects. The specific types of objects struck and the severities of the resulting injuries are listed in Table 5-21. The level of injury severity ranged from no injury (property damage only) to one evident injury.

Table 5-21. SeaTac Phase 4 – Fixed-Object Accident Characteristics Before Project Construction

	Before	After*	
	8 crashes 8 fixed objects	X crashes X fixed objects	
Fixed Objects	<ul style="list-style-type: none"> • Curb/traffic island (1) • Earth bank or ledge (1) • Fire plug (1) • Guardrail face (1) • Mail box (1) • Utility pole (2) • Wood sign post (1) 	<ul style="list-style-type: none"> • 	
Severity of Fixed-Object Accidents	<ul style="list-style-type: none"> • Fatal (0) • Disable (0) • Evident Inj (1) • Possible Inj (1) • PDO (6) 	<ul style="list-style-type: none"> • Fatal () • Disable () • Evident Inj () • Possible Inj () • PDO () 	

*After data for 2006-2008 will be available in 2009

The fixed-object collision experience can be described in terms of a “fixed-object collision rate,” similar to the accident rate described above, by using Equation 3.

For SeaTac Phase 4 before the redevelopment, this calculation results in a rate of 2.75 fixed-object collisions per 10 million vmt. This rate is similar to those of other sections of SR 99 prior to redevelopment, which were frequently between 1.5 and 4 fixed-object collisions per 10 million vmt.

Injury Severity

The level of injury sustained during all types of crashes ranged from no injury to two disabling injuries and one fatality, as listed in Table 5-22. The two disabling injuries resulted from vehicular accidents involving 1) a left turn across the opposing direction of traffic and 2) a rear-end collision. As noted above, the one fatality was a pedestrian south of the intersection with S. 200th Street, with the vehicle traveling in the southbound direction. The accident occurred after dark, at 7:36 PM in October with streetlights on.

The fatal and disabling injuries accounted for 2.9 percent of all accidents. This is higher than on most other sections of SR 99, although still lower than the statewide average of 3.0 percent disabling plus 0.6 percent fatal accidents. Within the Northwest Region, the disabling accidents accounted for 2.3 percent and fatal accidents for 0.3 percent; the Phase 4 section of SeaTac was lower than this combined experience.

Table 5-22. SeaTac Phase 4 – Injury Severities Before Project Construction

	Before	After*	
Fatal	1		
Disabling Injury	2		
Evident Injury	15		
Possible Injury	26		
Property Damage Only	61		
Total	105		

**After* data for 2006-2008 will be available in 2009

Pedestrian and Bicyclist Accidents

Before construction of the Phase 4 project, one bicyclist was struck at a mid-block location, resulting in some injury to the bicyclist. In addition, there were four pedestrian accidents, three of them also at mid-block locations. One of these resulted in a fatal injury to the pedestrian and occurred south of the intersection with S. 200th Street. The remaining pedestrian accidents resulted in some level of non-disabling injuries to the pedestrians.

Speeds

Spot speed studies were conducted at mid-block locations prior to the project's construction. In 2000 and 2002 the 85th percentile speeds in these studies ranged from 46 to 52 mph. The speed limit is 45 mph. Additional speed studies conducted following construction of this project will be used to evaluate any changes in travel behavior following this redevelopment.

Phase 4 Summary

In conclusion, existing conditions within this phase of the International Boulevard redevelopment project were not markedly different from those of the other phases within SeaTac. The types of crashes, levels of injury, and locations were all similar to those of the other phases. Given that there is only one intersection, and it experienced fewer accidents than many of the intersections in other phases of the redevelopment project, the accident rate within this phase was lower, although it was very close to the rate within

Phase 2 prior to redevelopment. The fixed-object rate was likewise lower than that for phases 1 or 2, although it was higher than the Phase 3 rate.

SeaTac Data Analysis Conclusions

One lesson learned from SeaTac's early redevelopment projects is that trees should not be placed close to intersections or left turn lanes. Within this project context, such placement resulted in frequent tree hits, necessitating repeated tree replacement and eventual removal of trees. SeaTac redesigned its landscaping plans following the construction of phases 1 and 2, and other cities have paid attention to these findings, deciding to not place trees within narrow medians approaching intersections and along left turn lanes.

Left turn signal phasing changes made in the Stage 1 and Stage 2 projects resulted in large increases in left turn accidents. The left turn signal phasing was changed from protected-only to protected/permitted at S. 200th Street and S. 170th Street during the projects. The new S. 192nd and S. 195th signals also experienced large increases in left turning accidents as a result of the protected/permitted signal phasing.

Prior to the construction of these projects, four U-turn collisions occurred (three were in Phase 1) within the three-year analysis timeframe. All of them resulted in no more than property damage. Following completion of the projects, this number increased to 35 (19 in Phase 1 and 16 within Phase 2) collisions within three years. The distribution of injuries included PDO (20), evident injury (7), and possible injury (8). The U-turn behavior change was highly probable, given the extent of the resulting restrictions on turning movements across the highway. According to Phillips et al. (2004), the changes in safety at intersections following the construction of a project replacing a TWLTL with medians are minimal. The evidence here suggests there was a significant increase in the frequency of accidents (and specifically U-turn accidents) and in injury severity. All of the collisions occurred at signalized intersections or at dedicated mid-block left/U-turn lanes. This is likely due to increased U-turn movements in response to access control measures.

The accident rates listed in Table 5-23 show that all phases of the SeaTac project exceeded statewide and regional accident rates for similarly classified roadways.

Following construction of the redevelopment project, the accident rate decreased in the Phase 1 roadway segment and increased in Phase 2.

Table 5-23. SeaTac –Accidents Rates Before and After Project Construction

	Before	After	
Phase 1	8.10	6.86	
Phase 2	3.63	5.64	
Phase 3	6.37		
Phase 4	3.57		

Following completion of additional projects along SR 99, the trends in accident rates and severities will be clearer. Currently, there is no evidence that the accident rate increase in Phase 2 is directly related to the planting of trees within the median and along the sidewalks.

An overall accident rate, fatality rate, and fixed-object collision rate can be computed for *before* and *after* conditions to determine general trends, given the different results from the individual project areas. These numbers are listed in Table 5-24.

Table 5-24. SeaTac Phases 1 and 2 – Summary Accident Rates

	Before	After	
Accident Rate	6.23	5.68	
Fatal Accident Rate	5.04	1.25	
Fixed-Object Collision Rate	4.03	3.88	

The accident rates presented in Table 5-24 were tested for independence with a chi-squared test and showed no statistically significant difference between the *before* and *after* conditions. However, the accident rates presented in Table 5-24 illustrate that throughout the combined project area, each accident rate decreased. Although safety, as measured by accident rates, did not decrease uniformly or significantly across the two project areas, there was a net improvement.

SEATAC MODELING RESULTS

Statistical models were developed to model the frequency and severity of accidents within project areas both before and after the construction of the SeaTac phase 1 and 2 streetscape redevelopment projects.

Accident Frequency Models

Accident frequencies are modeled with Poisson or negative binomial models, as discussed in the literature review and methodology sections. In all of the final models, the dispersion parameter, α , was not significant (t-stat <1.96), so it was concluded that the data were not overdispersed and the Poisson regression model was appropriate.

The available variables were investigated in a variety of combinations. The variables that were investigated most closely included average daily traffic (ADT), the intersection indicator, the presence of driveways on one or both sides of the road, the level of access control, horizontal and vertical curvature, the widths and types of medians, types of turn lanes, and the presence of trees.

The discussions in the sections above illustrate that intersections have higher concentrations of accidents than mid-block locations. To address the possibility that the intersection variable might be the strongest predictor of accident frequencies, we first developed models that included all accidents within the Phase 1 and Phase 2 project areas, and then excluded the accidents at all intersections. This allowed us to investigate the effects of the streetscape redevelopment projects on the entire redeveloped route, as well as at mid-block sections, which underwent significant changes in geometry and traffic movements. In addition, SeaTac phases 1 and 2 were analyzed together because of the similarity in the features of the redevelopment projects and the overall length of these sections, which together measured approximately 2 miles. Issues of heteroskedacity could have arisen with shorter sections because of variations in accident frequencies along the sections caused by differences between intersections and mid-block areas.

Initially, four frequency models were developed, two for the *before* conditions and two for the *after* conditions. The modeling results are presented below in tables 5-25 through 5-28. The independent and indicator variables that were significant in the final models are discussed to shed light on the tendency of these variables to increase or

decrease the frequency of accidents. The descriptive statistics and correlation matrices for the variables included in the final models are presented in Appendix C.

SeaTac Phases 1 and 2 Before Conditions

The results described in tables 5-25 and 5-26 represent conditions existing before construction of the SeaTac phases 1 and 2 streetscape redevelopment projects.

Variable	Average ADT (daily traffic volumes averaged over three years)
Finding	A strong tendency to increase the frequency of accidents with increasing volumes
Model(s)	Both with and without intersections

Traffic volume was chosen to represent exposure to the possibility of accidents. The positive coefficient for the average traffic volume along the project section indicates that with higher traffic volumes, the frequency of accidents increased. This is a reasonable expectation, given that there are more opportunities for conflicting movements, and thus the probability of a collision increases, where a greater number of vehicles are within the same time and space.

Table 5-25. SeaTac Before – Poisson Regression Model with Intersections

Independent Variable		Coefficient (t-stat)	
Constant		-2.1833 (-4.3540)	
Average ADT	Average daily traffic volumes, averaged over the three year timeframe	0.96556E-04 (8.0900)	
Vertical Grade	Vertical grade back in %	-0.26888 (-4.3700)	
Horizontal Curvature Angle	The outside horizontal angle in degrees	0.23566 (1.9680)	
Intersection	Indicator for an intersection, typically signalized	1.5287 (8.7210)	
Turn East	Indicator for either a south left-turn or a north right-turn lane	0.70767 (5.4110)	
East Access Control	Controlled access indicator as defined by the presence of sidewalk w/o a driveway or intersection	-0.56760 (-3.1970)	
Wide East Shoulder	Indicator for east shoulder width greater than 3'	-0.49934 (-3.9070)	
Wide West Shoulder	Indicator for west shoulder width greater than 3'	-0.56436 (-4.4130)	
Curb	Indicator for a curb separating lanes	-0.42881 (-3.2170)	
Df	Degrees of freedom	9	
Number of observations		196	
Restricted Log-Likelihood		-912.179	
Log-Likelihood at Convergence		-577.120	

Table 5-26. SeaTac Before – Mid-Block Poisson Regression Model

Independent Variable		Coefficient (t-stat)	
Constant		-1.2510 (-2.1840)	
Average ADT	Average daily traffic volumes, averaged over the three year timeframe	0.5602E-04 (4.1160)	
Vertical Grade	Vertical grade back in %	-0.21668 (-3.4320)	
Turn East	Indicator for either a south left-turn or a north right-turn lane	0.72305 (5.3230)	
East Access Control	Controlled access indicator as defined by the presence of sidewalk w/o a driveway or intersection	-0.51257 (-2.8710)	
Curb	Indicator for a curb separating lanes	-0.38982 (-2.8580)	
West Shoulder Width	The width of the shoulder along the west roadside	-0.05227 (-2.0890)	
Bus Stop	Indicator for a bus stop in either the northbound or southbound direction	0.24332 (1.7280)	
Df	Degrees of freedom	7	
Number of observations		185	
Restricted Log-Likelihood		-461.026	
Log-Likelihood at Convergence		-422.686	

Variable	Vertical Grade Back (VGB)
Finding	A tendency to reduce accidents
Model(s)	Both with and without intersections

This variable represented the vertical slope of the roadway. The Vertical Grade Back and Vertical Grade Ahead variables were significant in many of the models investigated. Given that VGB and VGA represented essentially the same information in opposite directions of travel, it was deemed appropriate to include only one of these variables in any model. The negative sign on the VGB coefficient indicates that with steeper grades, the likelihood of accidents decreased. The grades varied between 0 and 4.3 percent, with less than 40 percent of the highway sections having any grade. Only 6 percent had grades of greater than 3 percent. Therefore, these grades were not likely to have significant effects on sight distances. All values were positive in the northbound direction of the highway, indicating a downward slope in the southbound direction. Separation of the accident frequencies for the increasing and decreasing directions of travel might provide interesting insights into differences in the effects of upward grades and downward grades. With the current model, it can be concluded that grades were significant.

Variable	Horizontal Angle
Finding	A tendency to increase accidents at locations with greater angles
Model(s)	Intersection model

The horizontal angle is measured in degrees from the outside of the curve in such a way that small angles represent wide curves and large angles represent tight curves. Thus, the finding of a positive association between the curve angle and accident frequency intuitively leads to a conclusion that more accidents occur at locations with greater curvature.

The SeaTac phases 1 and 2 highway sections had little variation in curvature; all sections were either straight or had a curve of 1 degree (to the right or left). This indicates that for the SeaTac phases 1 and 2 data, more accidents occurred on the curved sections, although the possible effects of greater curvature on the frequency of accidents cannot be extrapolated. In addition, it cannot be determined whether the accidents occurred on the outsides or insides of curves, given that the data did not indicate the locations of accidents with respect to the roadway geometry, e.g., the direction of travel.

Variable	Intersection Indicator
Finding	A strong tendency to increase accidents
Model(s)	Intersection model

As shown in the summary statistics in the previous section, intersections had accident frequencies that, combined, accounted for anywhere from 46 to 83 percent of the accidents within the project areas. Other research (Sullivan 2004) has shown that significantly different factors affect the frequency of accidents at intersections than affect the frequency of accidents at mid-block locations.

The primary reason that intersections experience significantly higher accident frequencies is that vehicles are exposed to conflicting traffic movements, which increases the probability of a collision. This research is not focused on how to address accident occurrences at intersections but, rather, on evaluating the overall safety of the roadway before and after the streetscape redevelopment projects.

Variable	Turning East Indicator
Finding	A tendency to increase the frequency of accidents
Model(s)	Both with and without intersections

There were more access points along the east side of the highway, and turning movements for these access points were accommodated by left turn lanes in the southbound direction, as well as by some northbound right turn lanes. The Turning East variable was a surrogate for the level of access on the east side, based on the higher frequency of eastward turning movements than westward turning movements. Other turn-lane and many access variables were not found to be significant.

Variable	East Access Control Indicator
Finding	Associated with reduced accident frequencies
Model(s)	Both with and without intersections

This variable represented degree of access control, as defined by the presence of sidewalks along the highway without any access point such as a driveway or intersection. The finding of a negative association between this variable and accident frequencies indicates that locations with more access control experience lower accident frequencies. Sidewalks define where pedestrians are intended to be and help define where vehicles should enter or exit the adjacent property. This positive guidance has the effect of creating a more predictable driving environment.

The west side of the highway had fewer access points and fewer sidewalks, and the East Access Control Indicator was not significant in the *before* models.

Variable	Wide East Shoulder Indicator
Finding	Associated with reduced accident frequencies
Model(s)	Intersection model

The shoulder provides space for the drivers who leave the roadway to regain control or bring the vehicle to a stop, preferably before encountering a roadside hazard. Intuitively, wider shoulders free of fixed objects provide more room and, thus, would be associated with fewer accidents. Because the data for shoulder width did not adequately capture the width of shoulders at intersections (besides specifying them as zero), variables representing shoulder widths of greater than 3 feet were created. These variables showed that shoulders wider than 3 feet significantly reduced the frequency of accidents. Shoulders wider than 2 feet were found to significantly reduce accidents as well; however, given that most highway sections with shoulders narrower than 2 feet

were at intersections, the correlation between the shoulder and intersection variables was high, so the >3-foot distinction was used.

Variable	Wide West Shoulder Indicator
Finding	Associated with reduced accident frequencies
Model(s)	Intersection model

As noted above, the shoulder provides room for errant vehicles to recover or stop without encountering fixed objects or curbs. The Wide West Shoulder variable was defined as a shoulder wider than or equal to 3 feet.

Variable	West Shoulder Width
Finding	A tendency to decrease accident frequency with greater widths
Model(s)	Model excluding intersections

This variable was included in the model when intersections were excluded. The finding confirms what was expected, that wider shoulders reduced accident frequency. The east shoulder width was not found to be significant; this could be related to the difference in the levels of access on the east and west sides of the highway. The west side had fewer access points because of SeaTac International Airport.

Variable	Bus Stop Indicator
Finding	Associated with increased accident frequencies
Model(s)	Model excluding intersections

The Bus Stop variable indicated the location of a bus stop on either the east or west side of the highway. The positive sign on the bus stop variable coefficient indicates that locations with bus stops experienced higher accident frequencies than locations without bus stops. Prior to the redevelopment projects, the bus stops were not well defined, and buses either stopped in the through-travel lane or pulled up on the shoulder to load or unload passengers. This situation resulted in vehicle conflicts, either with the buses themselves or between other vehicles maneuvering around them. In the redevelopment projects, bus pullouts were provided at all stop locations.

Variable	Curb Indicator
Finding	A tendency to reduce the frequency of accidents
Model(s)	Both with and without intersections

The Curb variable indicated where lanes were separated by a curb adjacent to the lane. Frequently this occurred along left turn lanes, both approaching intersections and along dedicated mid-block left turn lanes and merging¹ lanes. The finding of a negative association between the frequency of accidents and the presence of a curb suggests that the separation of the travel lanes reduced conflicts by reducing exposure to opposing directions of travel. This suggests that the medians installed during the construction of the redevelopment projects may positively affect the frequency of accidents by separating the directions of travel along a greater portion of the project section.

SeaTac Phases 1 and 2 After Conditions

The models presented in tables 5-27 and 5-28 represent conditions following construction of the SeaTac phases 1 and 2 streetscape redevelopment projects. The variables significant in these models are discussed below.

Table 5-27. SeaTac After – Poisson Accident Frequency Model with Intersections

Independent Variable		Coefficient (t-stat)	
Constant		0.46561 (0.9500)	
Average ADT	Average daily traffic volumes, averaged over the three year timeframe	0.23117E-04 (1.8690)	
Vertical Grade	Vertical grade back in %	-0.55678 (-6.8670)	
Intersection	Indicator for an intersection, typically signalized	1.5950 (7.4820)	
Turn East	Indicator for either a south left-turn or a north right-turn lane	0.44039 (4.1390)	
West Access Control	Controlled access indicator as defined by the presence of sidewalk w/o a driveway or intersection	0.69608 (3.3940)	
Lane Separation	Indicator for separation between the directions of travel, either landscaped median or curb	-1.8129 (-9.8790)	
Total Trees	The total number of trees within the median, and along both sides of the street within a 50' section	-0.15887 (-3.2350)	
Df	Degrees of freedom	7	
Number of observations		196	
Restricted Log-Likelihood		-1125.113	
Log-Likelihood at Convergence		-526.412	

¹ Several locations accommodate left-in and left-out movements to driveways on the east side of the highway. The center turn lane along SR 99 at these locations is curbed to provide a dedicated southbound left turn lane and then a merge lane into the southbound traffic, with an asphalt island separating these turning movements.

Table 5-28. SeaTac After – Mid-Block Poisson Accident Frequency Model

Independent Variable		Coefficient (t-stat)	
Constant		-2.6570 (-3.1400)	
Average ADT	Average daily traffic volumes, averaged over the three year timeframe	0.37724E-04 (1.6690)	
Vertical Grade	Vertical grade back in %	-0.25822 (-2.6370)	
Turn East	Indicator for either a south left-turn or a north right-turn lane	0.84039 (3.5960)	
West Access Control	Controlled access indicator as defined by the presence of sidewalk w/o a driveway or intersection	0.79379 (3.2790)	
Curb	Indicator for a curb separating lanes	-0.71468 (-2.2300)	
Landscaped Median	Indicator for a landscaped median of any width (4' - 12') planted with trees	-0.71640 (-2.6840)	
Both Driveways	Indicator for the presence of east and west driveways within the same 50' highway section	1.4009 (3.9100)	
East Trees	Number of trees along the east sidewalk	0.30801 (2.5720)	
Df	Degrees of freedom	8	
Number of observations		170	
Restricted Log-Likelihood		-199.931	
Log-Likelihood at Convergence		-175.855	

Variable **Average ADT** (daily traffic volumes averaged over three years)
Finding A strong tendency to increase the frequency of accidents with increasing volumes
Model(s) Both with and without intersections

As noted in the discussion of the *before* conditions, the positive coefficient for the average traffic volume along the project section indicates that with higher traffic volumes, the frequency of accidents was likely to be higher.

Variable **Vertical Grade Back**
Finding A tendency to reduce accidents
Model(s) Both with and without intersections

As noted above, the negative sign on the VGB coefficient indicates that with steeper grades, the likelihood of accidents decreased. Separating the accident frequencies for the increasing and decreasing directions of travel might provide some interesting insights into any differences in the effects of upward grades and downward grades. The grades, and the effects they had on accident frequencies, did not change from the *before* to the *after* conditions.

Variable	Intersection Indicator
Finding	A strong tendency to increase accidents
Model(s)	Intersection model

As discussed above, the primary reason that intersections experience significantly higher accident frequencies is that vehicles are exposed to conflicting traffic movements, which increases the probability of a collision.

Variable	Turning East Indicator
Finding	A tendency to increase the frequency of accidents
Model(s)	Both with and without intersections

As noted above, the Turning East variable was a surrogate for the level of access along the east side that generated turning movements and potential conflicts. Turning movements for access points were accommodated by left turn lanes in the southbound direction, as well as by some northbound right turn lanes. Other turn-lane variables were not found to be significant.

Variable	West Access Control Indicator
Finding	Associated with increased accident frequencies
Model(s)	Both with and without intersections

The West Access Control variable had a significant positive association with accident frequencies, indicating that locations along the west with less access control experienced lower accident frequencies. The variable was specified as a value of 1 at locations with a sidewalk and no access point, and all other locations were given a zero value. If in fact the few access points along the west side were a significant factor contributing to increased accident frequencies, then it would be expected that the West Driveway variable would be significant.

Variable	Lane Separation Indicator
Finding	A tendency to reduce the frequency of accidents
Model(s)	Intersection model

This variable was defined as any separation between the opposing directions of travel, including curb and landscaped medians of all widths. As suggested above in the *before* conditions, separating the directions of traffic reduces the exposure to conflicting traffic movements, thus reducing the probability of a collision.

A variety of variables indicating different median widths and types (e.g., landscaped, curb, wide, narrow) were investigated during the modeling. None of them were found to be significant in the final model that included intersections.

Variable	Curb Indicator
Finding	A tendency to reduce the frequency of accidents
Model(s)	Model excluding intersections

The Curb variable indicated where lanes were separated by a curb adjacent to the lane. In the *after* conditions, this occurred along some left turn lanes approaching intersections, and along dedicated, mid-block left turn and merging lanes (as described above). The finding of a negative association between the frequency of accidents and the presence of a curb suggests that the separation of the travel lanes reduced conflicts by reducing the exposure to opposing directions of travel.

Variable	Total Trees
Finding	A tendency to reduce the frequency of accidents
Model(s)	Intersection model

This variable represented the total count of trees within a section, i.e., the number of trees within the median plus the number along the east and west sides of the highway. The variable ranged from zero to eight trees per 50-foot section.

Some might interpret this finding as suggesting that the presence of trees reduces accident frequencies; specifically, the more trees the better. However, we must look more closely at the locations where trees were and were not planted. First and foremost, trees were not within intersections, which were shown to significantly increase the frequency of accidents. Thus, trees were within sections that had fewer accidents to begin with. Second, there were fewer or no trees along sections that had driveways or turn lanes. Therefore, the sections likely to have the most trees were those with the fewest opportunities for conflicting movements, and vice versa. This does not negate the finding of a negative association between the number of trees present within a section and the frequency of accidents; it simply offers an explanation for the result. Sections that had the same degree of access control and separation between the opposing directions of travel – but no trees – could be expected to have the same accident frequencies (all else being equal).

Variable	Landscaped Median Indicator
Finding	A tendency to reduce the frequency of accidents
Model(s)	Model excluding intersections

The Landscaped Median variable was defined as any section of median that had some type of plant material growing in it. This included wide and narrow medians.

The Lane Separation variable showed little variation in this model, given that most of the mid-block sections had some type of lane separation. Therefore, the Curb and Landscaped Median variables were included in the non-intersection model, and both were found to significantly contribute to a reduction in accident frequencies.

The significance of this variable confirms previous research (Phillips et al. 2004) that installing medians in place of a two-way left turn lane reduces the frequency of accidents at mid-block locations. As discussed regarding the Total Trees variable, it is difficult to separate the effects of the landscaping from the effects of access control improvements.

Variable	Indicator of driveways on both sides of the highway
Finding	A tendency to increase the frequency of accidents
Model(s)	Model excluding intersections

This variable related to level of access. Independently, the driveway variables were not significant. However, locations that had driveways on both sides of the highway had a statistically significant higher number of accidents than locations with at most one driveway. Although such locations do not necessarily behave as four-way intersections (i.e., not all movements are allowed), they still increase exposure to conflicting movements and, thus, increase the probability of collisions.

Variable	East Trees
Finding	A tendency to increase the frequency of collisions
Model(s)	Model excluding intersections

The East Trees variable was a count variable representing the number of trees along the east shoulder within a 50-foot section. The number ranged from zero to four trees per section. As discussed above, the east side of the highway had more access points than the west side, and access points are typically related to increased accident frequencies.

Some might suggest that the East Trees variable masked the effects of access points (i.e., the presence of a driveway was the cause of accidents, not the trees). However, because these variables were inversely related i.e., there were more trees within sections without driveways, this is unlikely. Vehicles make movements into and out of the driveways, passing the trees as they do so. Therefore, one could interpret this variable as an interaction between access and the presence of trees. The limitation of visibility from or to the driveways is one possible contributing factor.

Comparing *Before* and *After* Conditions

The findings from the models discussed above indicate the most significant factors affecting the frequency of accidents along the SeaTac phases 1 and 2 project sections, both with and without intersections. The Average ADT, Vertical Grade Back, and Turning East variables were within all models, with coefficients that had consistent signs. In addition, at least one variable representing the separation of the directions of travel (curb, lane separation, and landscaped median) was included within each model, contributing to reduced accident frequency.

The variables that changed from the *before* to the *after* conditions are the related to mid-block access control (East Access Control and West Access Control). Before redevelopment, access control along the east side of the highway tended to decrease the frequency of accidents. Given that most of the highway did not have sidewalks to help control access, this finding indicates that access control may play a particularly significant role in reducing accident frequencies. However, in the *after* conditions, the West Access Control variable was significant in both models, associated with an increase in accident frequencies.

The Bus Stop indicator variable was significant in the *before* model of mid-block locations, contributing to an increase in the frequency of accidents. The fact that this variable was not significant in the *after* conditions indicates that there was a probable improvement in safety at bus stop locations. As noted above, improvements at bus stop locations that were part of the redevelopment projects included bus pullouts² and better

² A bus pullout is a curbside lane added at bus stops that allows transit vehicles to pull out of the through-travel lanes while they load and unload passengers.

definition of bus stops. In addition, most of the bus stops were re-located from mid-block locations to the far side of intersections.

Variables relating to shoulder width were significant in the *before* models. Following redevelopment, shoulders were narrowed to 1 to 2 feet along most of the project section to allow for sidewalks and to improve the aesthetic qualities of the roadway (i.e., a narrower streetscape with vertical definition provided by the street trees was desired). Therefore, variation in these variables was insufficient to use them in the models. In addition, the Wide Shoulder variables used in the *before* models defined a narrow shoulder as less than or equal to 3 feet; when narrow shoulder variables were included in the *before* model instead of the Wide Shoulder variables, they significantly contributed to increased accident frequencies. (The Wide Shoulder variables were included in the final model on the basis of the chi-square statistic.) Therefore, it can be concluded that there was a probable increase in accidents in the *after* conditions caused by narrow shoulder width.

The tree variables produced interesting results, as the total number of trees tended to reduce the frequency of accidents in the model, including at intersections, while trees along the east sidewalk tended to increase accidents when intersections were excluded. To better understand the effects of trees on accident frequency, subsequent analyses were undertaken.

As described above, SeaTac provided maintenance reports of trees replaced within the phases 1 and 2 project areas. Within the 1999 to 2001 analysis time frame, 36 median trees were replaced, 90 percent reportedly because of being struck by vehicles. These incidents represent interactions between vehicles and median trees. Although they may not have resulted in sufficient damage to the vehicle or occupant to warrant being reported to the police as a collision, the fact that an incident was not reported does not necessarily mean that it was not sufficiently damaging to warrant being reported as a collision. This is because accidents in general are under-reported, including tree collisions.

The tree maintenance reports can be used in recalculating the fixed-object collision rates. The fixed-object rates for phases 1 and 2 before and after the projects'

construction are presented in Table 5-29, along with the collision rates for the combined sections.

Table 5-29. Fixed-Object Collision Rates Including Tree Incidents

	Before	After	
Phase 1	3.90	3.28	
Phase 2	5.48	3.38	
Combined	4.03	3.88 ³	
Including tree incidents		7.74	

The fixed-object collision rate for the two projects indicates an overall decrease in the rate of collisions with fixed objects. However, if tree incidents are included in the *after* rate, it equals 7.74 fixed-object collisions per 10 million vmt, a significant increase in the rate of incidents. As noted, many of the accidents involving trees may not have resulted in significant injuries, or possibly even very much property damage, given that the trees were small. It is also noteworthy that the majority of median trees replaced were within narrow medians or at the end of a wide landscaped median near a mid-block left turn lane or T-intersection. Regardless of median width, at these locations the medians are exposed to more vehicular turning movements than the typical mid-block sections.

Injury Severity Models

Accident injury severity models were developed by using the multinomial logit (MNL) method (discussed in the literature review and methodology sections). The injury severities were split into three discrete choice categories, following the structure laid out by Holdridge et al. (2005) and Shankar et al. (1995): property damage only (PDO), injury accidents (evident, disabling, and fatal injuries), and possible injuries. One of the limitations in the data that led to this structure was the low frequency of fatal and disabling injury accidents. Combining all injury levels provided sufficient data to estimate coefficients.

³ Having an average that is greater than the two numbers averaged is an artifact of how accident rates are calculated. The length of the Phase 2 project is less than 1 mile, and thus it was excluded from the accident rate calculations. When the project sections were combined, the lengths were added and, therefore, the combined accident rate shifted.

SeaTac Phases 1 and 2 Before and After Conditions

The variables were investigated in a variety of combinations. Individual variables were used; some variables were stratified to determine more specific effects; and interactions between variables were developed to determine more precise causes of accident injury severities. The results of the modeling are presented in Table 5-30.

Table 5-30. SeaTac Before and After – Accident Injury Severity Utility Functions

Variable	Before Coefficient (t-stat)			After Coefficient (t-stat)		
	PDO	Injury	Possible Injury	PDO	Injury	Possible Injury
Constant		-2.1763 (-8.511)	-0.8697 (-5.132)		-2.6063 (-6.890)	-0.5156 (-4.644)
Rear end accident	-1.0439 (-4.989)					
Rear end accident at an intersection					0.6612 (1.610)	
Opposite direction accident		1.1584 (2.569)			2.1901 (5.493)	
Same direction sideswipe accident	0.9781 (2.470)			1.1028 (2.851)		
Accident with only one car	2.1310 (2.231)		2.9290 (3.012)	-1.0264 (-1.985)		
Accident with more than two cars		0.6197 (1.786)			0.9867 (2.705)	
At least one pedestrian or bicyclist involved		6.1162 (5.849)			3.5988 (5.429)	
DUI accident involving at least one driver over 65		1.4334 (2.629)			2.3359 (2.991)	
DUI accident between 7pm and 5am				2.6454 (2.534)		3.1213 (2.881)
Accident occurred between 7pm and 5am	0.5226 (2.457)					
Accident occurred on wet road between 7pm and 5am		0.5455 (1.548)				
One or more drivers were at least partially ejected		5.4449 (3.747)				
Lane separation – curb and/or median or any type		-0.7526 (-2.252)			1.0381 (2.727)	
Accident involving at least one fixed object		3.0320 (4.133)				-3.4518 (-3.150)
Number of trees on west side of road				0.6248 (2.319)		
Total Probabilities	54.34%	15.34%	30.31%	54.61%	19.15%	26.24%

The descriptive statistics and correlation matrices for the variables included in the final models are presented in Appendix C.

The Hausman test for the independence of irrelevant alternatives (IIA) was applied to determine whether there were any shared, unobserved variables among the injury severity categories. However, when the test was performed the models failed to converge, indicating that the Hessian was non-positive definite at the start value.

The overall probabilities of each injury severity category are presented at the end of Table 5-30 for the *before* and *after* conditions. These results, shown as the percentage of all accidents that would be expected to result in each injury severity level, indicate an increase in the probability of injury accidents and a decrease in the probability of possible injuries. Property damage accidents were equally probable before and after the streetscape redevelopment projects were constructed. A chi-square test of the difference in these injury severity distributions showed no statistically significant difference.

Variable	Rear-End Accident
Finding	A tendency to decrease the probability of PDO accidents in <i>before</i> conditions
Utility Function(s)	PDO (before)

This variable can be interpreted as follows: the occurrence of a rear-end accident tends to result in more damage than to property only, i.e. some type of injury (although in this model rear-end accidents were not significant in increasing injury or possible injury accidents). In the *before* conditions, rear-end accidents occurred at intersections and mid-block locations, while in the *after* conditions, rear-end accidents were concentrated at intersections, as discussed below.

Variable	Rear-End Accident at an Intersection
Finding	A tendency to increase the probability of injury in <i>after</i> conditions
Utility Function(s)	Injury (after)

Before project construction, the occurrence of a rear-end accident was associated with reduced property damage, while after reconstruction, it was associated with an increase in injuries when the rear-end accident occurred at an intersection. This may be related to changes in the locations of rear-end accidents.

Variable	Opposite Direction Accident
Finding	A tendency to increase the probability of injuries in both <i>before</i> and <i>after</i> conditions
Utility Function(s)	Injury (before and after)

A collision that involves vehicles traveling in opposite directions is associated with an increased probability for injuries. The closing speed in these accidents is likely to be greater than in many same-direction accidents, which results in greater deceleration upon impact and greater forces on the individuals in the vehicles.

Variable **Same Direction Sideswipe Accident**
Finding A tendency to increase the probability of PDO accidents in both *before* and *after* conditions
Utility Function(s) PDO (before and after)

This variable was associated with an increased probability for property damage. The split in sideswipe accidents between those that occur in the same direction and those that occur in opposite directions produced a significant result. That is, when the variables were combined, Sideswipes contributed to decreased possible injury accidents, but when separated, the Same Direction Sideswipes variable resulted in increased PDO accidents, and the opposite direction variable dropped out. When vehicles collide in a sideswipe collision there is less direct impact. The smaller force transferred to the drivers reduces their probability of sustaining injuries.

Variable **Accident with one car**
Finding A tendency to increase the probability of PDO and possible injury accidents in *before* conditions, and decrease PDO accidents in *after* conditions
Utility Function(s) PDO (before), Possible Injury (after)

Single-vehicle collisions were associated with increased probability of PDO and possible injury accidents in *before* conditions and a reduced probability of PDO accidents in *after* conditions. This change may indicate that the severity of single-vehicle collisions decreased following the completion of the streetscape projects. This agrees with the analysis of fixed-object collision injury severity, which found that the severity of fixed-object collisions (a sub-set of single-vehicle collisions) decreased.

Variable **Accident with more than two cars**
Finding A tendency to increase the probability of injuries in both *before* and *after* conditions
Utility Function(s) Injury (before and after)

The Multiple Vehicle variable was associated with an increased probability for injuries. This is related to an increased number of individuals who may be injured in a multi-vehicle collision, as well as the potential for greater force between two or more vehicles.

Variable **At least one pedestrian or bicyclist involved**
Finding A tendency to increase the probability of injuries in both *before* and *after* conditions
Utility Function(s) Injury (before and after)

As noted previously, pedestrians and bicyclists are often most severely injured in collisions. Pedestrians and bicyclists sustained 11 of the study's 27 fatal or disabling injuries; only one pedestrian or bicyclist accident did not result in any injury. This variable indicating that at least one individual involved in the collision was not in a motorized vehicle was associated with an increased probability of injury.

Variable **DUI accident involving at least one driver over 65 years old**
Finding A tendency to increase the probability of injuries in the both *before* and *after* conditions
Utility Function(s) Injury (before and after)

This interaction between age and sobriety in a collision indicated that collisions involving at least one driver under the influence of alcohol and at least one driver over the age of 65 increased the probability of an injury. This variable did not stipulate that the same individual be older than 65 *and* under the influence. The interaction may be related to the increased vulnerability to injury of many older individuals.

Variable **DUI accident occurring between 7:00 PM and 5:00 AM**
Finding A tendency to increase the probability of PDO and possible injury accidents in *after* conditions
Utility Function(s) PDO, Possible Injury (after)

The interaction between the hours of darkness and a driver under the influence of alcohol was related to an increased probability of property damage or possible injury accidents. Because approximately 71 percent of DUI accidents in the *after* conditions occurred during the night hours, the traffic volumes associated with most of those accidents were lower than those associated with accidents that occurred during peak periods or mid-day. Therefore, although most of those accidents occurred at night, they

likely involved fewer multi-vehicle collisions, which have been shown to increase the probability of injury. This explains the increase in PDO and possible injury accidents.

Variable **Accident occurring between 7:00 PM and 5:00 AM – Night**
Finding A tendency to increase the probability of PDO accidents in *before*
 conditions
Utility Function(s) PDO (before)

As noted above, traffic volumes are lower during the night hours, thus reducing exposure to other vehicles. Collisions occurring during night hours are more likely to result in property damage only than collisions at other times of day (all else being equal).

Variable **Night time accident occurred on wet road**
Finding A tendency to increase the probability of injury in *before* conditions
Utility Function(s) Injury (before)

The interaction between night conditions and wet roadways increased the probability of injury – i.e., a collision that occurred at night on a wet road was more likely to result in an injury than one that occurred either on a dry road or during the day. This variable represented a subset of the Night Accident variable discussed above, and yet they were both significant in the same model of the *before* conditions in their respective utility functions. The combined effects of reduced visibility at night, possibly with rain and glare, and wet pavement are likely to create situations in which drivers do not see another vehicle, object, or a pedestrian in time to safely avoid them, or they are unable to stop, given the reduced friction of wet pavement. Higher closing speeds are also likely, resulting in greater injury.

Variable **One or more drivers at least partially ejected from a vehicle**
Finding A tendency to increase the probability of injury in *before* conditions
Utility Function(s) Injury (before)

The Ejection indicator variable was defined as 1 if any driver was partially or fully ejected from a vehicle and 0 otherwise. In all, 15 accidents involved ejected drivers, all before construction. Ejection indicates that large forces have been exerted on the driver, and such force is likely to result in injuries to the ejected driver or other individuals involved in the accident.

Variable	Lane Separation
Finding	A tendency to decrease the probability of injuries in <i>before</i> conditions, and increase the probability of injuries in <i>after</i> conditions
Utility Function(s)	Injury (before and after)

The Lane Separation indicator variable was defined as 1 for any location that had a curb or a median or any width, including landscaped medians. Before construction, this variable was associated with a reduced probability of an injury. This is likely the case because curbs are typically installed at potentially high-conflict points, such as along turn lanes, to reduce conflicts that occur near access points. Injuries likely in such conflicts are avoided as well.

After construction, 97 percent of the mid-block sections had some type of lane separation. However, only 20 percent of the *after* accidents occurred at locations with lanes separated by a curb or median. This might suggest that the Intersection variable was significant in the injury utility function, but it was not. One possible explanation for the tendency of the Lane Separation variable to increase the probability of injuries is that it indicated is the presence of a median or curb within the roadway, which is likely to be struck in single- or multi-vehicle collisions.

Variable	Accident involving at least one fixed object
Finding	A tendency to increase the probability of injury in <i>before</i> conditions and decrease the probability of a possible injury in <i>after</i> conditions
Utility Function(s)	Injury (before), Possible Injury (after)

Colliding with a fixed object before construction tended to increase the probability of injuries. As discussed in the literature review, fixed-object accidents are frequently severe, and this was corroborated here.

Following the completion of the streetscape projects, the Fixed-Object variable was associated with a reduction in possible injury accidents. This is not a contradiction of the previous findings but indicates a weaker relationship between accident severity and fixed-object incidents. Given the descriptive analysis of the collisions with fixed objects above, this would not be unexpected with young, small trees.

Variable	Number of trees on west side of road
Finding	A tendency to increase the probability of PDO accidents in <i>after</i> conditions
Utility Function(s)	PDO (after)

As noted above, trees affect the frequency of accidents, and this variable shows that they likewise affect the severity of accidents. Planting trees along the west side of the roadway evidently had the effect of increasing the probability of property damage accidents. Given the relatively small size of the trees during the analysis timeframe, this finding suggests that interactions with trees are not severe. Subsequent analyses will be used to determine what, if any, change in accident severity is associated with larger trees within this urban context.

CHAPTER 6

FEDERAL WAY REDEVELOPMENT

PROJECT DESCRIPTION

The City of Federal Way developed a Comprehensive Plan in 1990 to revitalize the city center. The plan included extensive streetscape redevelopment along many city roads, including the section of SR 99 known as Pacific Highway. The objectives of the plan were to improve traffic and pedestrian safety and circulation, support transit and carpool use, provide landscaping, and enhance the overall aesthetics of the urban route. The desired aesthetic improvements included trees within the median and along the sidewalks. Therefore, the city chose to participate in the In-Service Evaluation agreement with WSDOT and assisted with the development of initial tree placement criteria and guidelines for the In-Service Evaluation.

The project is being constructed in two phases: the first from S. 310th Street to S. 324th Street and the second from S. 324th to S. 340th Street. Improvements include widening the existing five-lane roadway to a seven-lane section, including two general-purpose lanes and one business access and transit (BAT) lane in each direction (beginning south of the intersection with S. 312th Street), and installing a landscaped median with provisions for left turn and U-turn movements at intersections and designated mid-block locations. The medians include trees planted within some sections. The project also includes pavement overlay. The typical cross-section is illustrated in Figure 6-1.

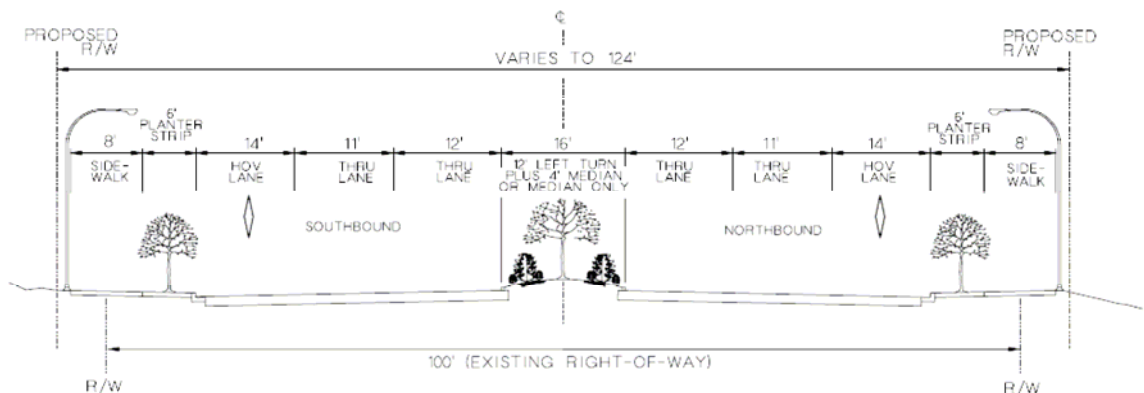


Figure 6-1. Federal Way – Typical Cross-section

Other elements include improvements to the pedestrian environment consisting of curbs, gutters, and sidewalks along both sides of the roadway. A 6-ft planter strip is separating the 8-ft sidewalk from the roadway in most locations, providing room for street trees and other landscaping, as shown in Figure 6-1. The aesthetics of the streetscape is being further improved by undergrounding all overhead utility distribution lines, with the exception of high electrical transmission lines, which will be relocated to new poles.

Phase 1 of the project was constructed between 2002 and 2004. Construction for Phase 2 is taking place in 2005 and is extending the improvements made in the earlier project. A third phase for the Federal Way redevelopment project will extend north of Phase 1 to the intersection with Dash Point Road. However, Phase 3 may not be included in this analysis because of its timing. The proximity of these projects to each other is illustrated in Figure 6-2.

Figure 6-3 shows *before* and *after* conditions to illustrate the differences in the streetscape. Note the access definition on the right-hand side of the road.

The landscaping plans in Federal Way preclude planting trees within narrow medians near intersections or along mid-block left turn lanes. These conditions are illustrated in photographs of the completed Phase 1 project, shown in Figure 6-4.

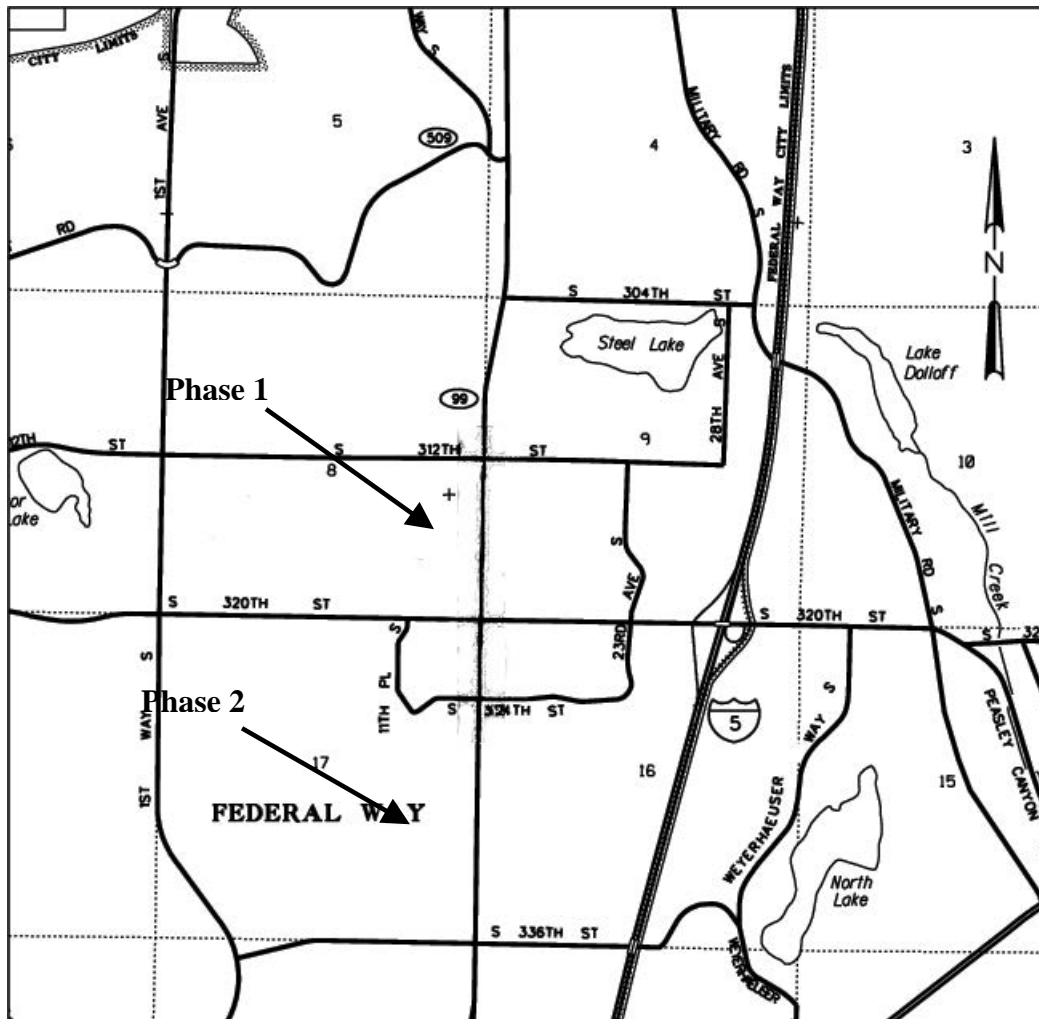


Figure 6-2. Federal Way – Pacific Highway Streetscape Redevelopment Project Vicinity Map



Figure 6-3. Federal Way Phase 2 – Before and After Redevelopment



**Figure 6-4. Federal Way Phase 1 – Completed Project with Left-Turn Pockets.
Note Narrow Medians without Trees**

DATA ANALYSIS

Phase 1 Data Analysis

The roadway environment changed significantly during the Phase 1 project construction, leading to expectations that the accident experiences will also change. Controlled access will change where vehicles enter and egress adjacent property, which will likely change the locations of accidents. Different types of fixed objects will be in the roadside environment: *before* conditions included utility poles and other highway facility hardware, whereas after development, trees, luminaire poles, and signal hardware will be more prevalent. This discussion analyzes accidents before the construction of Phase 1 of Federal Way's streetscape redevelopment project. The data for the *after* conditions will become available in 2007.

Accident Types

Prior to project construction, 423 accidents occurred in the 0.92-mile Phase 1 section between 1999 and 2001. There were no fatal accidents, but three bicyclists and eleven pedestrians were involved in accidents. All of the pedestrian accidents occurred at intersections or driveways. Five of the eleven were at the intersection with S. 320th Street, and two were at the intersection with S. 312th Street. Two of the pedestrians were under the influence of alcohol, and 19 of the drivers were under the influence of alcohol. Two of the bicyclists were struck at the intersection with S. 324th Street, resulting in possible or evident injuries. Table 6-1 summarizes this information.

Table 6-1. Federal Way Phase 1 – Accident Characteristics Before Project Construction

	Total Accidents	Fatal	Bikes	Peds	DUI
Before	423	0	3	11	19
After*					

3 years of data collected for *before* analysis

Section length = 0.92 miles

**After* data for 2004-2006 will be available in 2007

Before project construction, the accident categories that each accounted for approximately 10 percent or more of the total accidents were rear-end accidents (46 percent), driveway related (19 percent), sideswipes (13 percent), and left turns (11 percent), as illustrated in Table 6-2.

Table 6-2. Federal Way Phase 1 – Predominant Accident Types Occurring Before Project Construction

	Rear End	Driveway Related	Sideswipe	Left Turns
Before	45.6%	19.1%	12.8%	11.1%
After*				

**After* data for 2004-2006 will be available in 2007

Accident Rates

Prior to Phase 1 construction, traffic volumes within the study section ranged from approximately 22,000 to 32,000 vehicles per day (vpd), with an average rate of 27,400 vpd. The accident rate calculated with Equation 1 is 14.11 accidents per million vehicle miles of travel (vmt) before redevelopment. The fatal accident rate would be calculated similarly if there were any fatal accidents within the project area and analysis timeframe.

The statewide average accident rate for highway facilities classified as Urban Principle Arterials (UPA) was 2.97 per million vmt in 1996. This section of SR 99 is within WSDOT's Northwest Region, and the average accident rate for all facilities in this region was 2.12 per million vmt. Likewise, within King County, the accident rate was 2.27 per million vmt, and the fatal accident rate was 0.58 per ten million vmt. From this it can be concluded that the overall accident rate along this section of SR 99 was higher than that on similarly classified routes and higher than those rates within the WSDOT

region and county for the analysis timeframe, exceeding the UPA accident rate by almost five times.

The accident rate of Federal Way's Phase 1 project prior to redevelopment was also higher than that of other sections of SR 99 in this analysis. As noted in Table 6-3, this section of SR 99 had four major intersections. The high accident counts associated with intersections make the overall accident rate higher than that of other sections of similar length with fewer intersections. In addition, one of the intersections in Federal Way's Phase 1 project experienced 120 accidents in three years, which was the highest accident count for any individual intersection along SR 99 within this analysis.

Accident Locations

As previously noted, there are four major signalized intersections within the Phase 1 section. They are listed in Table 6-3 with the number of accidents at each of them.

Table 6-3. Federal Way Phase 1 – Intersection and Driveway Accident Characteristics Before Project Construction

	Total Intersections	Total at Driveways	Mid- Block	324 th 9.68	320 th 9.94	316 th 10.18	312 th 10.44	
Before	4 ~69.0%	17.0%	14.0%	54	120	49	57	
After*	4							

*After data for 2004-2006 will be available in 2007

As noted above, the number of accidents at the intersection with S. 320th Street was unusually high. This investigation is not analyzing intersections; if, following the construction of this project, the experience at this intersection does not significantly improve, such analysis is highly advisable. The remaining Phase 1 intersections had numbers of accidents similar to those at other intersections within the SR 99 projects under analysis.

Fixed-Object Collisions

Before project construction, eight fixed-object crashes occurred within the Phase 1 section, as listed in Table 6-4. The severity of these crashes was low, with only one individual reporting any injury, and the remaining crashes resulting in only damaged property. Six of the fixed-object crashes occurred at intersections.

Table 6-4. Federal Way Phase 1 – Fixed-Object Accident Characteristics Before Project Construction

	Before	After*	
	8 crashes 8 fixed objects	X crashes X fixed objects	
Fixed Objects	<ul style="list-style-type: none"> • Curb or traffic island (3) • Metal sign post (1) • Luminaire pole (2) • Utility pole (2) 	<ul style="list-style-type: none"> • 	
Severity of Fixed-Object Accidents	<ul style="list-style-type: none"> • Fatal (0) • Disable (0) • Evident Inj (0) • Possible Inj (1) • PDO (7) 	<ul style="list-style-type: none"> • Fatal () • Disable () • Evident Inj () • Possible Inj () • PDO () 	

*After data for 2004-2006 will be available in 2007

The one-year report on Phase 1 from Federal Way describes the removal of one tree within the median approaching the intersection with S. 320th Street from the north. This tree was removed because of complaints that it obstructed sight distance for the left turn lane at the intersection. No other data indicated any tree-strikes or limited sight distance due to the landscaping within the medians.

A “fixed-object collision rate” can be calculated to describe the frequency of fixed-object incidents along different sections of SR 99. Equation 3 is used to calculate this rate.

For Federal Way’s Phase 1 project, this calculation results in a value of 2.67 fixed-object collisions per 10 million vmt. This rate is similar to that of many of the other SR 99 sections prior to construction of the redevelopment projects. Given that the severity levels of the accidents involving fixed objects was low, it can be concluded that the rate of accidents with fixed objects before construction was better than most.

Injury Severity

The frequencies of each level of injury severity are listed in Table 6-5. As noted above, there were no fatalities. However, two pedestrians sustained disabling injuries in two right turn collisions. A same-direction sideswipe and an entering-at-angle accident also resulted in disabling injuries.

Table 6-5. Federal Way Phase 1 – Injury Severities Before Project Construction

	Before	After*	
Fatal	0		
Disabling	4		
Evident Injury	35		
Probable Injury	124		
Property Damage Only	260		
Total	423		

**After data for 2004-2006 will be available in 2007*

The accidents resulting in disabling injuries represented 0.9 percent of all accidents. In comparison to other SR 99 sections, this is a small percentage, as disabling injuries in other sections were between 2 and 3 percent of all accidents. Likewise, a comparison to the statewide disabling injury accident rate, which accounts for 3.0 percent (2.3 percent in the Northwest Region) of all accidents, shows that the accidents within Federal Way's Phase 1 project resulted in relatively low percentage of injuries. Therefore, despite the markedly high accident rate, there is no evidence that the severity of these accidents was likewise high.

Pedestrian and Bicyclist Accidents

As noted above, three bicyclists and eleven pedestrians were involved in accidents before the construction of Federal Way's Phase 1 project. All of the pedestrian accidents occurred at intersections or driveways. Five of the eleven were at the intersection with S. 320th Street, and two were at the intersection with S. 312th Street. Two of the pedestrians were under the influence of alcohol, and two sustained disabling injuries. In addition, two of the bicyclists were struck at the intersection with S. 324th Street, resulting in possible or evident injuries.

Speed Studies

Spot speed studies were conducted in 2005 at a mid-block location following the completion of Phase 1 construction. The 85th percentile speeds recorded in this study ranged between 39 and 43 mph, with a maximum recorded speed of 54 mph (1 vehicle was observed at this speed). The posted speed limit through Federal Way is 40 mph.

Actual speed data were not available for the period before project construction. However, it can be concluded that within Federal Way there is no evidence that the median had a negative impact on travel speeds, given that the travel speeds were neither far below nor far above the posted speed limit. WSDOT and Federal Way consider both excessive speeding and speeds significantly below the speed limit undesirable because of the impacts on the safety and efficiency of the route.

Phase 2 Data Analysis

The roadway environment changed significantly during the Phase 2 project construction, leading to expectations that accident occurrences will also change. Controlled access will change where vehicles enter and egress adjacent property, which is likely to change the locations of accidents. Different types of fixed objects will be in the roadside environment: *before* conditions included utility poles and other highway facility hardware, whereas after development, trees, luminaire poles, and signal hardware will be more prevalent. This analysis discusses accident occurrences before the construction of Phase 2 of Federal Way's streetscape redevelopment project. The data for the *after* conditions will become available in 2008.

Accident Types

A total of 213 accidents occurred in the 1.02-mile section of Phase 2 between 2000 and 2002 prior to project construction. This included one fatal accident, one crash involving a bicyclist, and six pedestrian accidents. One of the pedestrians was the casualty in the fatal accident, and the driver of the involved vehicle was under the influence of alcohol. In addition, nine other drivers were under the influence of alcohol. Table 6-6 summarizes this information.

Table 6-6. Federal Way Phase 2 – Accident Characteristics Before Project Construction

	Total Accidents	Fatal	Bikes	Peds	DUI	
Before	213	1	1	6	10	
After*						

3 years of data collected for *before* analysis

Section length = 1.02 miles

**After* data for 2005-2007 will be available in 2008

Accident Rates

Prior to Phase 2 construction, traffic volumes within the study section ranged from approximately 14,000 to 33,000 vehicles per day, with an average rate of 27,800 vpd. Before redevelopment, the accident rate calculated with Equation 1 was 6.85 accidents per million vmt. The fatal accident rate was calculated by using a similar equation, Equation 2.

The fatal accident rate for Phase 2 was 3.22 per 10 million vmt, calculated with the understanding that there was only one fatality within the project area and analysis timeframe. The statewide average accident rate for highway facilities classified as Urban Principle Arterials was 2.97 per million vmt in 1996. This section of SR 99 is within WSDOT's Northwest Region, and the average accident rate for all facilities in this region was 2.12 per million vmt. Likewise, within King County, the accident rate was 2.27 per million vmt, and the fatal accident rate was 0.58 per 10 million vmt. From this it can be concluded that both the 1996 overall accident rate and the fatal accident rate along this section of SR 99 were higher than those on similarly classified routes and higher than those within the WSDOT region and county for the analysis timeframe.

The accident rate of Federal Way's Phase 2 project prior to redevelopment was higher than that of most of the other sections within this analysis, as well as higher than the statewide and regional averages. However, it was much lower than the Phase 1 accident rate. Part of the difference between the Phase 1 and 2 projects may be attributable to the number of intersections within these projects. There were two major intersections in the Phase 2 section and four within the Phase 1 section.

Accident Locations

Table 6-7 lists the two signalized intersections within the Phase 2 project area. Overall, 47 percent of all accidents were related to intersections, while 22 percent were related to driveways. The number of accidents at S. 330th Street was low in comparison to that at many of the other intersections within this analysis. Given that no specific traffic volume data were recorded at this location (they were recorded at 333rd instead, although it is un-signalized), it can be concluded that the traffic volumes added or subtracted at this location were not significant, resulting in low exposure to opposing traffic.

Table 6-7. Federal Way Phase 2 – Intersection and Driveway Accident Characteristics Before Project Construction

	Total Intersections	Total at Driveways	Mid-Block	336 th	330 th	
Before	2 ~ 46.5%	22.1%	31.5%	54	18	
After*						

*After data for 2005-2007 will be available in 2008

The mid-block accident experience was high in comparison to other sections of SR 99 within this analysis. In addition to the fact that there were few intersections within this project area, the distribution of accidents along the project section indicated a greater number accidents between intersections than on many other sections of SR 99.

The accident categories that each accounted for more than 10 percent of total accidents are listed in Table 6-8 and include rear-end accidents (47 percent), driveway related (20 percent), and sideswipes and left turns (11 percent each). These categories are similar to those of other SR 99 sections, and the frequencies are also similar. However, the “driveway-related” rate was higher than that on many other sections, as was the “left turn” accident frequency.

Table 6-8. Federal Way Phase 2 – Predominant Accident Types Occurring Before Project Construction

	Rear End	Driveway Related	Sideswipe	Left Turns	
Before	47.4%	20.2%	11.3%	10.8%	
After*					

*After data for 2005-2007 will be available in 2008

Fixed-Object Collisions

Eight fixed-object accidents involving nine objects occurred within the Phase 2 project area, as listed in Table 6-9. The types of objects struck included curb or traffic islands and a tree, although this was prior to the project landscaping. The tree crash did not result in any injury to the driver. The severity of injuries in all the fixed-object crashes ranged from property damage only to two evident injuries, which resulted from incidents involving a wood signpost and roadway ditch.

Table 6-9. Federal Way Phase 2 – Fixed-Object Accident Characteristics Before Project Construction

	Before	After*	
	8 crashes 9 fixed objects	X crashes X fixed objects	
Fixed Objects	<ul style="list-style-type: none"> • Curb/traffic island (2) • Wood sign post (2) • Misc object (2) • Tree or stump (1) • Other object (1) • Roadway ditch (1) 	<ul style="list-style-type: none"> • 	
Severity of Fixed-Object Accidents	<ul style="list-style-type: none"> • Fatal (0) • Disable (0) • Evident Inj (2) • Possible Inj (1) • PDO (5) <p>Tree crash resulted in property damage only</p>	<ul style="list-style-type: none"> • Fatal () • Disable () • Evident Inj () • Possible Inj () • PDO () 	

*After data for 2005-2007 will be available in 2008

The “fixed-object” collision rate for Phase 2 was also calculated with Equation 3. This rate was 2.58 fixed-objects per 10 million vmt. This rate was lower than the rate of 2.67 for Phase 1, although the Phase 2 severity level was higher—three injuries from eight collisions in Phase 2 in comparison to one injury from eight collisions in Phase 1. Both of these fixed-object rates were similar to the fixed-object rates from other sections of SR 99 prior to redevelopment.

Injury Severity

The severity of injuries of all accidents within the project area prior to construction ranged from property damage to four disabling injuries and one fatality. As mentioned above, the fatality was a pedestrian. The disabling injuries included three additional pedestrians, two of whom were within 100 feet of each other and the fatal pedestrian collision (at the unsignalized T-intersection with S. 333rd Street at milepost 9.10). The remaining disabling injury involved the driver of vehicle 2 in a two-car crash in which driver 1 was under the influence of alcohol. Table 6-10 shows the frequencies of each injury severity level.

Table 6-10. Federal Way Phase 2 – Injury Severities Before Project Construction

	Before	After*	
Fatal	1		
Disabling	4		
Evident Injury	15		
Probable Injury	64		
Property Damage Only	129		
Total	213		

*After data for 2005-2007 will be available in 2008

The fatal and disabling injuries represented 2.3 percent of all accidents. This rate was higher than that of Phase 1 but similar to those of other sections of SR 99 within this analysis. The disabling injuries alone accounted for 1.9 percent of all accidents, which was lower than the 2.3 percent within the Northwest Region or 3.0 percent statewide.

Pedestrian and Bicyclist Accidents

Six accidents involved pedestrians, and one crash involved a bicyclist. One of the pedestrians was the casualty in the fatal accident, and the driver of the involved vehicle was under the influence of alcohol. As noted above, three of the other pedestrians sustained disabling injuries in accidents that occurred in close proximity to the fatal pedestrian accident.

Speed Studies

No speed studies were conducted before the construction of Phase 2. *After* studies should still be conducted to investigate travel speeds following the construction of this project. Although there will be no direct *before-after* comparison, the speeds recorded can be compared with the speed limit and travel speeds on other sections of SR 99 that have been redeveloped.

Federal Way Conclusions

The accident rate in Phase 2 was lower than that in Phase 1, prior to the construction of Federal Way's streetscape redevelopment projects. However, they both exceeded the accident rate of similarly classified facilities. In addition, the fatal accident rate for Phase 2 (there were no fatal accidents within Phase 1 during the analysis period)

exceeded the fatal accident rate for similarly classified facilities. The number of major intersections in each phase of the project, and the number of accidents at each intersection, contributed to the difference in accident rates. In particular, S. 320th Street in Phase 1 had a significantly higher number of accidents (120) than the other intersections, which ranged from 18 to 57. This explains some of the difference in accident rates presented in Table 6-11.

Table 6-11. Federal Way – Average Accidents Before Project Construction

	Before	After*	
Phase 1	14.11		
Phase 2	6.86		

**After* data will be available in 2007 and 2008

As noted previously, the fixed-object collision rates in both Federal Way projects were similar to rates in the remaining sections of SR 99 prior to redevelopment. Injury severities were relatively low, although they were higher in Phase 2 than in Phase 1.

Speed studies prior to the construction of these projects were not available. However, it is recommended that *after* speed studies be undertaken to investigate travel behavior following the redevelopment.

The locations of pedestrian and bicyclist accidents were concentrated at intersections. The pedestrian accident occurrence was high in comparison to the other SR 99 project areas before project construction; these conditions should be monitored carefully after the streetscape redevelopment projects have been completed.

FEDERAL WAY MODELING RESULTS

Modeling will be conducted after data become available in 2007 and 2008.

CHAPTER 7 DES MOINES REDEVELOPMENT

PROJECT DESCRIPTION

The Des Moines Pacific Highway (SR 99) redevelopment project, extending from the Kent-Des Moines Road to S. 216th Street (see Figure 7-1), took place in 2003-2004. The purpose of the project was to improve safety along Pacific Highway.



Figure 7-1. Des Moines – Pacific Highway Redevelopment Project Vicinity Map
(Source: City of Des Moines website - <http://66.175.4.144/maps/maps.html>)

The characteristics of the project included widening the road to seven lanes (two general-purpose lanes in each direction, one business access and transit (BAT) lane in each direction, and a landscaped median with mid-block left turn pockets and left turn lanes at the intersections); installing two new signals at S. 220th Street and S. 224th Street; constructing curbs, gutters, and sidewalks; erecting pedestrian and street lighting; and installing a new storm drainage system. This project was fully funded through a variety of federal, state, and local agency grants, as well as city funds. Figure 7-2 illustrates a

typical cross-section through Des Moines, and Figure 7-3 illustrates some of the changes made during the project.

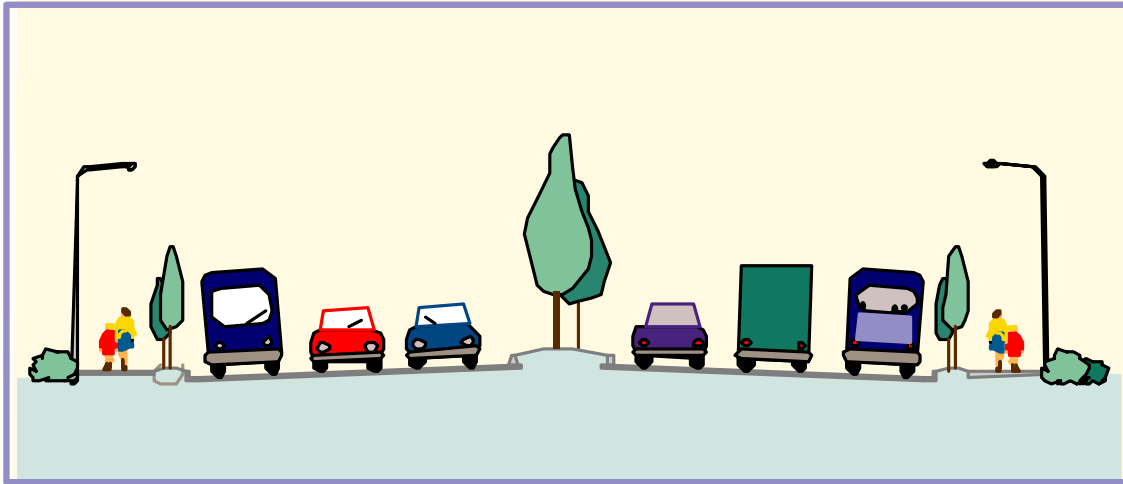


Figure 7-2. Des Moines – Typical Cross-Section



Figure 7-3. Des Moines – Before and After Photos

Discussions of the elements that were important to the community resulted in the decision to install a low profile barrier¹ (shown in Figure 7-4) along the landscaped median, rather than using a 6-in. curb and participating in the In-Service Agreement with WSDOT. Although Des Moines was not part of the In-Service Evaluation, it willingly participated in the Median Tree Evaluation study by providing information about its design decisions and attending meetings concerning this evaluation.

¹ The low profile barrier is an 18-in. barrier that WSDOT may accept as mitigation for the effects of fixed objects within the design clear zone for facilities with speeds of 35-45 mph.



Figure 7-4. Des Moines – Low-Profile Median Barrier to Mitigate the Effects of Trees and Decorative Objects

DATA ANALYSIS

The roadway environment changed significantly during the construction of the Des Moines project, leading to expectations that the accident occurrence will also change. Controlled access will change where vehicles enter and egress adjacent property, which is likely to change the locations of accidents. Different types of fixed objects will be in the roadside environment: *before* conditions included utility poles and other highway facility hardware, whereas after development, trees, luminaire poles, and signal hardware will be more prevalent. This analysis discusses accident occurrences before project construction. The data following construction will be available in 2008.

Accident Types

In the 1.12-mile-long section of the Des Moines SR 99 redevelopment project, 237 accidents occurred between 2000 and 2002, the three years before project construction. This number included one bicyclist accident and nine accidents involving pedestrians; none of these were fatal, although two of them resulted in disabling injuries

to the pedestrian. Four of the pedestrian accidents occurred at the SR 516 interchange. In total, nine of the vehicle drivers were under the influence of alcohol, as were two of the pedestrians. Table 7-1 summarizes the general characteristics of the accidents that occurred before redevelopment.

Table 7-1. Des Moines - Basic Accident Characteristics Before Project Construction

	Total Accidents	Fatal	Bikes	Peds	DUI	
Before	237	0	1	9	9	
After*						

3 years of data collected for *before* analysis

Section length = 1.12 miles

**After* data for 2005-2007 will be available in 2008

Within the entire project area, the categories of accidents that accounted for approximately 10 percent or more of all accidents included rear-end accidents (46 percent), driveway related (15 percent), and sideswipe (13 percent). In addition, left turn accidents accounted for 9 percent, and right turn accidents accounted for 8 percent, as shown in Table 7-2.

Table 7-2. Des Moines – Predominant Accident Types Occurring Before Project Construction

	Rear End	Driveway Related	Sideswipe	Left Turns	Right Turn	
Before	46.0%	14.8%	13.1%	9.3%	8.0%	
After*						

**After* data for 2005-2007 will be available in 2008

Accident Rates

Prior to project construction, traffic volumes along Des Moines' section of SR 99 varied between approximately 25,000 and 32,000 vehicles per day (vpd), with an average volume of 28,800 vpd along the project section. WSDOT calculates accident rates on the basis of traffic volumes and accident experience by using Equation 1.

For Des Moines before redevelopment, this calculation results in an overall accident rate of 6.70 accidents per million vehicle miles of travel (vmt). Given that there

were no fatal accidents within the analysis timeframe, the fatal accident rate is zero. The statewide average accident rate for highway facilities classified as Urban Principle Arterials in 1996 was 2.97. This section of SR 99 is within WSDOT's Northwest Region, and the average accident rate for all facilities in this region was 2.12 per million vmt. Likewise, within King County, the accident rate was 2.27 per million vmt. From this it can be concluded that the overall accident rate along this section of SR 99 was higher than that on similarly classified routes and higher than those within the WSDOT region and county for the analysis timeframe.

In comparison to other sections of SR 99 within this analysis and prior to any redevelopment projects, Des Moines' accident rate was in the mid-range of accident rates. Thus, although it exceeded the statewide and regional accident rates noted above, it was not unusual for this route.

Accident Locations

There were two signalized intersections within the project area, one with the SR 516 interchange at the southern city limit, and the other with S. 216th Street at the northern end. A total of 70 percent of all accidents were related to intersections, and 15 percent were related to driveways. The intersection with SR 516 experienced 88 accidents within three years, and the intersection with S. 216th had 37 accidents, as summarized in Table 7-3.

Table 7-3. Des Moines – Intersection and Driveway Accident Characteristics Before Project Construction

	Total Intersections	Total at Driveways	Mid Block	SR 516 15.49	224 th St** 16.02	220 th St** 16.28	216 th St 16.51
Before	2 ~ 70.0%	14.8%	14.8%	88	12	9	37
After*	4						

*After data for 2005-2007 will be available in 2008

**These two locations were signalized as part of the project

Two intersections were signalized as part of the project: S. 224th and S. 220th streets. Prior to signalization, the intersection with S. 224th Street experienced 12 accidents within three years. All other sections of the highway experienced nine or fewer accidents, and only three of these points experienced between five and nine accidents.

The numbers of accidents at the signalized intersections were similar to those at intersections within the SeaTac sections, which typically fell between 40 and 80.

Fixed-Object Collisions

Additional accident characteristics within this section included 10 fixed-object accidents involving 11 objects. The specific characteristics of the types of objects struck and the injury severity levels involved in fixed-object crashes are presented in Table 7-4.

Table 7-4. Des Moines – Fixed-Object Accident Characteristics Before Project Construction

	Before	After*
	10 crashes 11 fixed objects**	X crashes X fixed objects
Fixed Objects	<ul style="list-style-type: none"> • Curb or island (2) • Wood sign post (2) • Luminaire pole (1) • Traffic signal (1) • Guardrail (1) • Tree or stump (1) • Boulder (1) • Fence (2) 	<ul style="list-style-type: none"> •
Severity of Fixed-Object Accidents	<ul style="list-style-type: none"> • Fatal (0) • Disable (1) – curb • Evident Inj (1) • Possible Inj (1) • PDO (7) <p>Tree crash resulted in an evident injury</p>	<ul style="list-style-type: none"> • Fatal () • Disable () • Evident Inj () • Possible Inj () • PDO ()

*After data for 2005-2007 will be available in 2008

**Note: one accident involved two objects (fence and luminaire pole)

The types of objects struck were similar to those in other project areas along SR 99. Seven of the ten crashes had no injuries, and none of the collisions resulted a fatality, although one did result in a disabling injury.

The accident involving a tree occurred as the vehicle turned from SR 516 onto SR 99 and swerved to avoid being hit by another vehicle that ran a red light. It resulted in evident injury to the driver. This was prior to the streetscape redevelopment and landscaping projects. The collision diagram shows that the tree was planted beyond the shoulder area.

The fixed-object collision experience can be described in terms of a “fixed-object collision rate,” similar to the accident rate described above, by using Equation 3.

For Des Moines before the redevelopment, this calculation results in a rate of 2.83 fixed-object collisions per 10 million vmt. This rate is similar to that of other sections of SR 99 prior to redevelopment, which were frequently between 1.5 and 4 fixed-object collisions per 10 million vmt.

Injury Severity

Table 7-5 lists the severities of the accidents that occurred before project construction. Seven disabling injuries occurred, two of which were to pedestrians struck in the accidents. All of the disabling injury accidents were at mid-block locations, with the exception of the fixed-object collision at the intersection with S. 216th Street. This disabling injury accident resulted when the vehicle struck a curb, island, or median; note that this was before the installation of the barrier median and curbed sidewalks, and that some curbing did exist before project construction.

Table 7-5. Des Moines – Injury Severities Before Project Construction

	Before	After*	
Fatal	0		
Disabling	7		
Evident Injury	22		
Probable Injury	71		
Property Damage Only	137		
Total	237		

*After data for 2005-2007 will be available in 2008

Disabling injuries accounted for 2.9 percent of all collisions. This percentage was comparable to that of other sections of SR 99. The 1996 State Highway Collision Report indicates that the percentage of disabling injuries was 3.0 percent statewide and 2.3 percent in the Northwest Region.

Pedestrian and Bicyclist Accidents

As noted above, nine accidents involved pedestrians and one involved a bicyclist before the construction of Des Moines' project. None of these were fatal, although two of them resulted in disabling injuries to the pedestrian. Four of the pedestrian accidents

occurred at the SR 516 interchange. In addition, two of the pedestrians involved in accidents were under the influence of alcohol.

Speeds

Before construction, spot speed studies conducted at mid-block locations in 2000 recorded 85th percentile speeds of between 47 and 50 mph. In 2005, following the completion of construction, mid-block spot speed studies were also conducted. The 85th percentile speeds recorded in these studies ranged from 44 to 47 mph. The posted speed limit of 45 mph did not change during or after the construction project. These data indicate that the travel speeds through Des Moines slowed following the streetscape redevelopment project.

Des Moines Conclusions

The accident rate prior to the construction of the Des Moines project was high in comparison to similarly classified routes within Washington, but was within the mid-range of accident rates among the SR 99 sections being redeveloped. Des Moines had a higher percentage of accidents involving right turning vehicles, totaling 8 percent in comparison to 2 to 5 percent in most other SR 99 project sections. On the other hand, driveway-related accidents accounted for a smaller percentage than in most other sections, 15 percent in comparison to 20 to 25 percent.

One of the primary points of interest within Des Moines' project is that the city chose to install a low-profile barrier along the median landscaped with trees, shrubs, and decorative objects. This barrier is anticipated to have a different effect on traffic and accident rates, and, in particular, it may affect pedestrian movements. Following completion of the project, initial results relating to travel speeds along this section of SR 99 indicate that traffic slowed.

DES MOINES MODELING RESULTS

Modeling will be conducted after data become available in 2008.

CHAPTER 8

KENT REDEVELOPMENT

PROJECT DESCRIPTION

The City of Kent's projects will widen Pacific Highway (SR 99) between S. 272nd Street and south of the intersection with the Kent-Des Moines Road (SR 516), a length of approximately 2.5 miles. The \$17 million projects were prompted by increasing delays due to traffic congestion and increasing vehicle accident rates due to uncontrolled driveway access.

The projects will reconstruct and widen the roadway, providing northbound and southbound business access and transit (BAT) lanes adjacent to the street curb. Improvements will also include the construction of concrete curbs, gutters, sidewalks, and a median to control and define driveway access and improve the pedestrian environment. Landscaping will be included along the roadside and within the median. Upgrading and interconnecting the existing traffic signals will also be undertaken, along with drainage and illumination system improvements. The streetscape improvements are illustrated in figures 8-1 and 8-2.

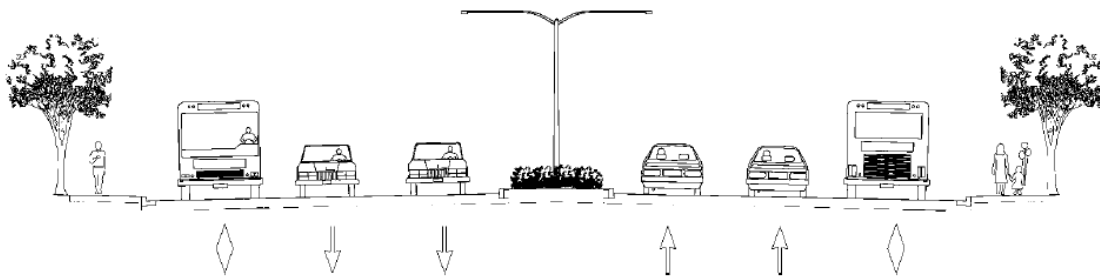


Figure 8-1. Kent – Cross-section of Pacific Highway Streetscape Redevelopment Project



Existing
South of S. 240th St.



Proposed
South of S. 240th St.

Figure 8-2. Kent – Before and After Conditions

The landscaping plans for these projects include drought-resistant shrubs in the median planting zones and street trees planted along the outside of the sidewalks. Given that there will be no trees within the median and a greater offset to the sidewalk trees, Kent did not elect to participate in the In-Service Evaluation Agreement with WSDOT. However, it has willingly participated in the Landscaped Median evaluation by providing information and participating in meetings. It has also made accommodations for a pedestrian crossing study conducted just north of the intersection with S. 240th Street near the Midway Drive-In Theater and Highline College.

The project is divided into two phases. The north phase is from the Kent-Des Moines Road to S. 252nd Street, and the south phase is from S. 252nd to S. 272nd Street. Given that these phases of the project will be constructed simultaneously in 2005-2006, the data analysis will treat them as one segment. Figure 8-3 shows the location of the project and illustrates its orientation to other regional features and infrastructure.

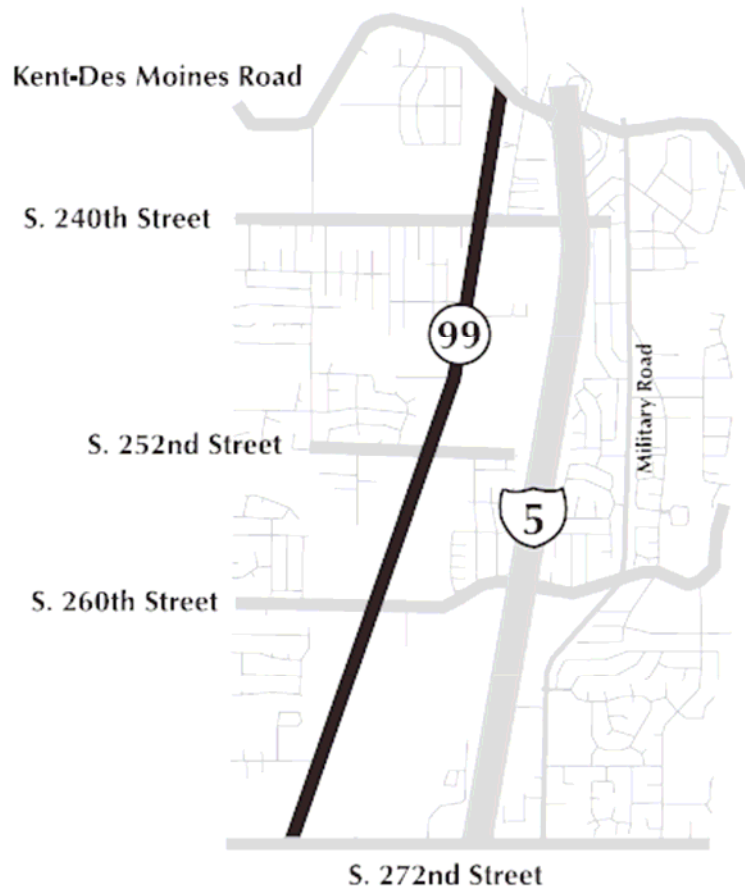


Figure 8-3. Kent – Pacific Highway Streetscape Redevelopment Project Vicinity Map

Figure 8-4 shows existing conditions at a mid-block location and the intersection with S. 240th Street.



Figure 8-4. Kent – Mid-block Location and Intersection Before Project Construction

DATA ANALYSIS

The roadway environment will change significantly during the construction of the Kent streetscape redevelopment project, leading to expectations that accident occurrences will also change. Controlled access will change where vehicles enter and egress adjacent property, which will likely change the locations of accidents. Different types of fixed objects will be in the roadside environment: *before* conditions included utility poles and other highway facility hardware, whereas after development, trees, luminaire poles, and signal hardware will be more prevalent. This analysis discusses accident occurrences before project construction; the data for *after* conditions will be available in 2010.

Accident Types

From 2002 to 2004, prior to the construction of these projects, 403 accidents occurred. The length of the highway section being improved is 2.48 miles. The accidents included one fatality and 12 pedestrian accidents involving 13 pedestrians, two of whom were under the influence of alcohol. Table 8-1 presents general accident characteristics, including the fact that 20 of the accidents involved drivers under the influence of alcohol.

Table 8-1. Kent - Basic Accident Characteristics Before Project Construction

	Total Accidents	Fatal	Bikes	Peds	DUI	
Before	403	1	0	12 ¹	20	
After*						

3 years of data collected for *before* analysis

Section length = 2.48 miles

**After* data for 2007-2009 will be available in 2010

¹Twelve accidents involving thirteen pedestrians

The fatal accident involved two vehicles at a mid-block, left turn location. The driver of the first vehicle was under the influence of alcohol. The first vehicle was rear-ended by the second and then overturned, resulting in a fatal injury to the driver.

The types of accidents that occurred most frequently (accounting for approximately 10 percent or more of all accidents) are listed in Table 8-2. They include rear-end accidents (54 percent), accidents related to driveways (21 percent), and sideswipes (10 percent). All other accident categories each represent less than 5 percent of the total accident experience.

Table 8-2. Kent – Predominant Accident Types Occurring Before Project Construction

	Rear End	Driveway Related	Sideswipe	
Before	53.6%	20.6%	9.9%	
After*				

*After data for 2007-2009 will be available in 2010

Accident Rates

The traffic volumes ranged from approximately 24,000 to 29,000 vehicles per day, with an average rate of 26,300 vehicles per day (vpd) along the project section prior to construction. The accident rates, based on traffic volumes and accident experience, are calculated with Equation 1, and fatal accident rates are calculated with Equation 2.

For Kent phases 1 and 2 before redevelopment, these calculations result in an overall accident rate of 5.64 accidents per million vehicles miles of travel (vmt), and a fatal accident rate of 1.40 per 100 million vmt. (Note: there was only one fatal accident in the analysis timeframe.)

The 1996 statewide average accident rate for highway facilities classified as Urban Principle Arterials was 2.97 per million vmt, and the fatal accident rate was 1.02 per 100 million vmt. This section of SR 99 is within WSDOT's Northwest Region, and the average accident rate for all facilities in this region was 2.12 per million vmt (the fatal accident rate in the Northwest region was 0.73 per 100 million vmt). Likewise, within King County, the accident rate was 2.27 per million vmt, and the fatal accident rate was 0.58 per 100 million vmt. From this it can be concluded that both the overall and fatal accident rates along this section of SR 99 were higher than those on similarly classified routes and within the WSDOT region and county for the analysis timeframe.

In comparison to other SR 99 sections within this analysis, the accident rate along Kent's project section was about average. However, Kent's fatal accident rate was the lowest of the fatal accident rates above zero. The evaluation of the accident severities presented below further illustrates the comparative levels of injury severities sustained by those involved in accidents along the SR 99 corridor.

Accident Locations

There are five signalized intersections within Kent's project area. A total of 86 percent of all accidents occurred at intersections, and 11 percent occurred at driveways. This is a relatively high proportion of intersection-related accidents in comparison to the other sections of SR 99 included in this analysis prior to redevelopment. The number of accidents occurring at the intersections within Kent ranged from 9 to 69 within three years. Table 8-3 lists the number of accidents at each intersection within the analysis timeframe.

Table 8-3. Kent – Intersection and Driveway Accident Characteristics Before Project Construction

	Inter- sections	Drive- ways	Mid Block	272 nd 12.92	260 th 13.71	Shops T-14.05	252 nd 14.24	240 th 15.00	
Before	5~86.1%	11.4%	2.5%	69	42	9	26	46	
After*	5								

*After data for 2007-2009 will be available in 2010

The numbers of accidents at each intersection were similar to the numbers at intersections along other SR 99 project areas, which generally fell between 40 and 80 accidents in three years.

No new signals are planned within Kent, but plans do include several dedicated left turn pockets at mid-block locations, and two locations that will allow both left-in and left-out movements from SR 99, as illustrated in Figure 8-5. Of particular note is the intersection with S. 268th Street. This location experienced 43 accidents within the three years before redevelopment. This rate is similar to those of many of the signalized intersections at other locations along SR 99, both within Kent and other cities. The property along this section of SR 99 is relatively undeveloped, with a few private homes, a public storage facility, and small commercial centers within about 1-quarter mile north and south. There is no center two-way left turn lane through this section.

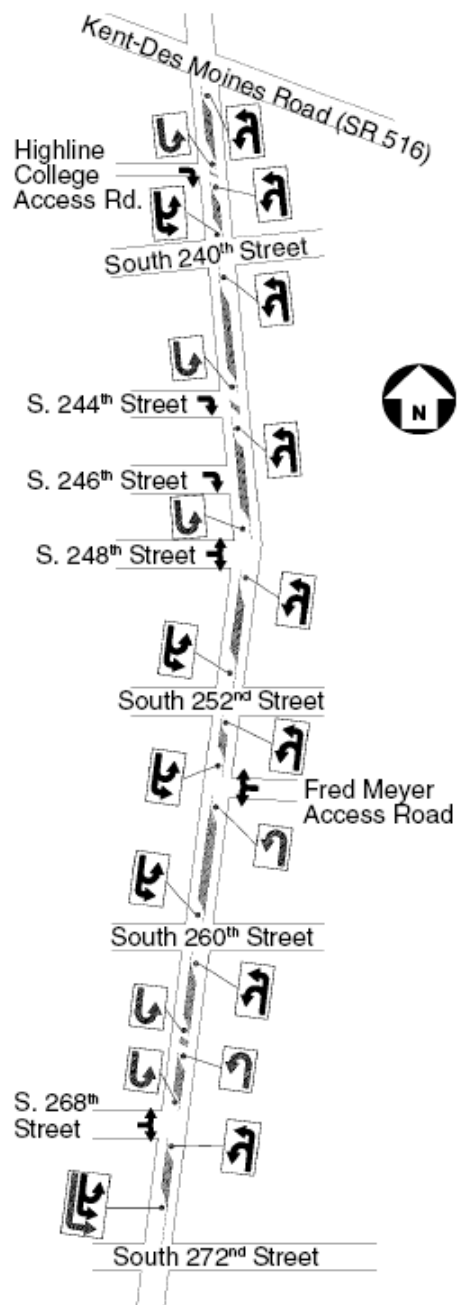


Figure 8-5. Kent – Channelization

Fixed-Object Collisions

Fixed-object crashes within Kent before redevelopment included 12 collisions with a variety of fixed objects, listed in Table 8-4. Half of these collisions occurred at intersections. The severity of all fixed-object collisions varied from no injuries to two in

which the drivers sustained injuries. In comparison to other sections of SR 99, this represents a relatively low number of fixed-object crashes, given that this section is about twice as long as most of the other sections. These accidents also had relatively low injury severities.

Table 8-4. Kent – Fixed-Object Accident Characteristics Before Project Construction

	Before	After*
	12 crashes 12 fixed objects	X crashes X fixed objects
Fixed Objects	<ul style="list-style-type: none"> • Retaining wall (1) • Utility Pole (4) • Traffic signal (4) • Building (2) • Fence (1) 	<ul style="list-style-type: none"> •
Severity of Fixed-Object Accidents	<ul style="list-style-type: none"> • Fatal (0) • Disable (0) • Evident Inj (2) • Possible Inj (3) • PDO (7) 	<ul style="list-style-type: none"> • Fatal () • Disable () • Evident Inj () • Possible Inj () • PDO ()

*After data for 2007-2009 will be available in 2010

The fixed-object collision experience can be described in terms of a “fixed-object collision rate,” similar to the accident rate described above, by using Equation 3.

For Kent before redevelopment, this calculation results in a rate of 1.68 fixed-object collisions per 10 million vmt. This rate is low in comparison to that in other sections of SR 99 prior to redevelopment, which were frequently between 2.5 and 4 fixed-object collisions per 10 million vmt.

Injury Severity

The severity levels of all accidents within the project area for the analysis timeframe are listed in Table 8-5. As noted above, there was one fatal rollover accident, and pedestrians sustained three of the disabling injuries. The remaining disabling injuries were sustained by drivers 1) in a head-on collision and 2) in a driveway-related accident in which a vehicle overturned. One potential benefit of the medians that will be installed as part of these redevelopment projects is the reduction in opportunities for head-on collisions, which frequently result in severe injuries.

Table 8-5. Kent – Injury Severities Before Project Construction

	Before	After*	
Fatal	1		
Disabling	5		
Evident Injury	25		
Probable Injury	115		
Property Damage Only	250		
Total	403		

**After data for 2007-2009 will be available in 2010*

In comparison to other SR 99 sections, Kent's section had a low fatal/disabling accident rate, accounting for 1.5 percent (6) of all accidents. Other project sections had between 2 and 7 percent fatal or disabling accidents. The average percentage on state highways within the Northwest Region is 2.6 percent for 1996 (the most recent collision severity statistics available from WSDOT).

Pedestrian and Bicyclist Accidents

Before construction of the Kent projects along SR 99 there were 12 pedestrian-related accidents involving 13 pedestrians. Five of the pedestrian accidents occurred at the intersection with S. 240th Street; one resulted in a disabling injury to a pedestrian, who was under the influence of alcohol. As noted above, a pedestrian crossing study is being undertaken near this location, which has a high volume of pedestrians. Three additional pedestrian accidents occurred at two other intersections. Two of the pedestrians struck at mid-block locations sustained disabling injuries.

No bicyclists were involved in collisions within the three-year analysis timeframe.

Speed Studies

Prior to project construction, spot speed studies were conducted at mid-block locations. The 85th percentile speeds recorded in these studies ranged from 43 to 48 mph in 2005, with a maximum speed recorded at 56 mph. Two locations had speeds ranging from 44 to 48 mph, while at the third location the 85th percentile speeds recorded were 43 and 44 mph. The speed limit throughout Kent is 45 mph. Speed studies should be conducted following completion of construction to determine the effect of the streetscape

redevelopment on the speeds of travelers along SR 99 through Kent.

Kent Conclusions

As noted above, *before* speed data are available for comparing *before* and *after* conditions once construction has been completed. It is noteworthy that different speeds were recorded at different mid-block locations, as listed in Table 8-6. This indicates that current conditions encourage slower speeds. Following the redevelopment project, it will be important to note speeds at similar locations.

Table 8-6. Kent – Speed Studies and Locations Prior to Redevelopment

Intersections		85 th percentile speeds (mph)	
SR 516-S 240 th Street		43, 43, 45, 43	
Location 1	S 240 th – S 252 nd Street	45, 48, 44, 44	
Location 2		48, 47, 44, 45	

The “fixed-object collision rate” for Kent prior to redevelopment was lower than that on most other sections of SR 99 within this analysis. Given that Kent chose to landscape its medians with drought-resistant shrubs instead of trees, this section of SR 99 will provide valuable data to compare with the sections that have medians landscaped with trees. Any change in the fixed-object collision rate will be interesting to observe and compare to changes in those rates on other sections landscaped with trees in the median and in closer proximity to the roadside.

KENT MODELING RESULTS

Modeling will be conducted after data become available in 2010.

CHAPTER 9

SHORELINE REDEVELOPMENT

PROJECT DESCRIPTION

The City of Shoreline's Aurora Corridor Project will redevelop the 3 miles of Aurora Avenue North (SR 99) that run through Shoreline. The project was initiated in response to high traffic volumes and accident rates that exceeded the statewide average for similarly classified facilities. The severity of those accidents contributed to the urgency of the project: on average one fatality occurred per year, and many of those were pedestrians (<http://www.ci.shoreline.wa.us/general/index.cfm?Article=571&Display=Detail>).

The goals of the plan are to improve pedestrian and vehicle safety, pedestrian and disabled access, vehicular capacity, traffic flow, transit speed and reliability, nighttime visibility and safety, storm water quality, economic investment potential, streetscape amenities, and the aesthetics of the road environment. The \$75 million project stretches from N. 145th Street to N. 205th Street and is split into two phases, as shown in Figure 9-1. Construction on the first phase, from N. 145th to N. 165th Street, began in 2005.



Figure 9-1. Shoreline – Aurora Corridor North Project Vicinity Map
(Source: http://www.wsdot.wa.gov/Projects/SR99/Shoreline_NCTHOV/map.htm)

Between 1998 and 2000 the City of Shoreline undertook an extensive pre-design study to investigate multi-modal needs along the Aurora Corridor. The study involved the public in dozens of public meetings, open houses, and presentations at City Council meetings. This process was enhanced by the creation and participation of the Citizen Advisory Task Force, comprising representatives from neighborhoods, the business community, and transit users.

Throughout the pre-design process, Shoreline was also involved with the In-Service Evaluation working group, assisting in the development of the tree-placement criteria and evaluation guidelines. Landscaping is a key component of the city's design, intended to strengthen the image of the roadway and increase the acceptability of the project by various stakeholders. Given its design priorities and decisions, the city chose to participate in the In-Service Evaluation with WSDOT.

Given the goals of the project, the roadway features in this redevelopment project include two through-lanes and a BAT lane in each direction, a landscaped median with lanes for left turn and U-turn movements at mid-block locations and intersections, and continuous street lighting. Figure 9-2 illustrates these features.

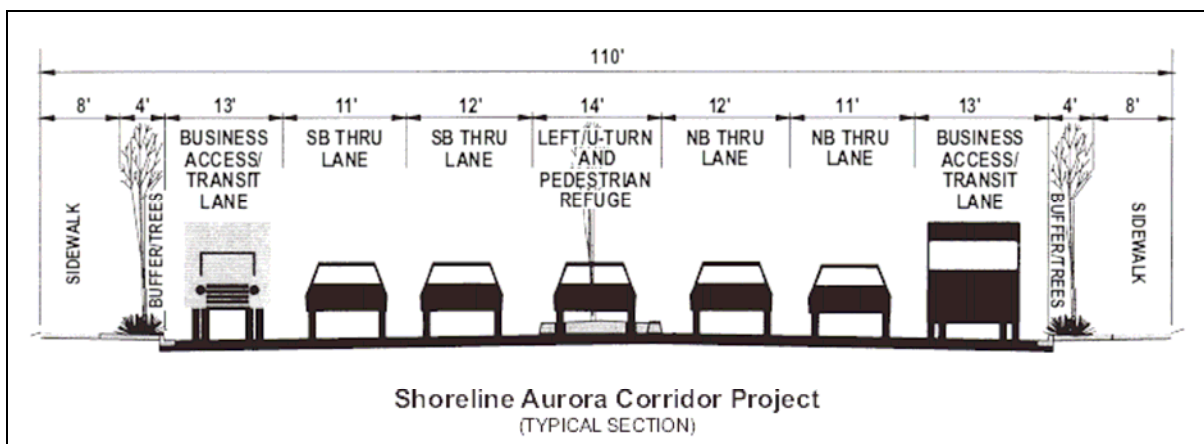


Figure 9-2. Shoreline – Typical Cross-Section

The pedestrian environment will be enhanced by continuous sidewalks, typically 7 feet wide, curbs and gutters, pedestrian-scale lighting at intersections, amenities such as benches, and landscaping in the 4-ft buffer region between the roadway and the sidewalk. Two pedestrian crossings will be installed or improved, and bus zones will be enhanced. Undergrounding the overhead utilities and landscaping the medians will also improve the

streetscape. Repaving and upgrading the stormwater facilities will also be part of these projects.

DATA ANALYSIS

The roadway environment will change significantly during the construction of Shoreline's project, leading to expectations that accident occurrences will also change. Controlled access will change where vehicles enter and egress adjacent property, which will likely change the locations of accidents. Different types of fixed objects will be in the roadside environment: *before* conditions included utility poles and other highway facility hardware, whereas after development, trees, luminaire poles, and signal hardware will be more prevalent. This analysis presents accident occurrences before construction of the streetscape redevelopment project; data illustrating conditions after project construction will be available in 2010.

Accident Types

In the three years before the beginning of redevelopment on Shoreline's Aurora Avenue, 337 accidents occurred within the 1.13-mile section. This number included one bicyclist accident at the intersection with N. 165th Street and three pedestrian accidents. One pedestrian sustained a disabling injury at the intersection with N. 165th Street, and the other two pedestrians were at mid-block locations and sustained evident injuries. There were no fatalities within the project area during the analysis timeframe (2002 to 2004). Eighteen of the accidents involved drivers under the influence of alcohol. These accident characteristics for the *before* conditions are recorded in Table 9-1.

Table 9-1. Shoreline – Basic Accident Characteristics Before Project Construction

	Total Accidents	Fatal	Bikes	Peds	DUI	
Before	337	0	1	3	18	
After*						

3 years of data collected for before and after analyses

Section length = 1.13 miles

*After data for 2007-2009 will be available in 2010

The predominant types of accidents (listed in Table 9-2) that accounted for

approximately 10 percent or more of all accidents were rear-end (48 percent), driveway related (20 percent), sideswipe (12 percent), and entering at angle (10 percent). These accident types and frequencies were comparable to those in other sections of SR 99 within this analysis prior to redevelopment.

Table 9-2. Shoreline – Predominant Accident Types Occurring Before Project Construction

	Rear End	Driveway Related	Sideswipe	Enter at Angle	
Before	47.5%	20.2%	11.6%	9.8%	
After*					

3 years of data collected for before and after analyses

Section length = 1.13 miles

*After data for 2007-2009 will be available in 2010

Accident Rates

Prior to construction of the first phase of the Shoreline project, traffic volumes within the study section ranged from approximately 33,000 to 39,000 vehicles per day, with an average rate of 36,100 vehicles per day (vpd). The accident rate based on these traffic volumes within the analysis period is calculated with Equation 1.

For the *before* conditions, this calculation results in an accident rate of 7.55 accidents per million vehicle miles of travel (vmt). The 1996 statewide average accident rate for highway facilities classified as Urban Principle Arterials was 2.97 per million vmt. This section of SR 99 is within WSDOT's Northwest Region, and the average accident rate for all facilities in this region was 2.12 per million vmt. Likewise, within King County, the accident rate was 2.27 per million vmt, and the fatal accident rate was 0.58 per 100 million vmt. From this it can be concluded that the accident rate along this section of SR 99 was higher than those on similarly classified routes and within the WSDOT region and county for the analysis timeframe. The high accident rate of this project section was cited as one of the primary reasons for initiating the project.

This rate was higher than most other sections of SR 99 within this analysis prior to redevelopment. The accident rates along other sections of SR 99 typically ranged from 5.5 to 6.5, although for Federal Way Phase 1 the rate was 14.1.

Accident Locations

Before construction of this redevelopment project, signalized intersections were at N. 145th, N. 155th, and N. 160th streets. Each of these intersections experienced between 47 and 67 accidents within the three-year analysis period. Overall, 86 percent of the accidents within the Aurora Corridor project were related to intersections. This is a higher proportion of intersection-related accidents than on most other sections of SR 99. Table 9-3 summarizes the numbers of accidents at the individual intersections, as well as along the entire project section.

Table 9-3. Shoreline – Intersection and Driveway Accident Characteristics Before Project Construction

	Inter- sections	Drive- ways	Mid Block	145 th 40.47	152 nd 40.80	155 th 40.97	160 th 41.23	165 th 41.48	
Before	3 ~85.8%	11.0%	3.3%	47	11	67	56	23	
After*	5 ~								

3 years of data collected for before analysis

*After data for 2007-2009 will be available in 2010

From November 2002 to January 2004, the intersection at N. 165th Street had a unique signal that was activated by the presence of a pedestrian. It was changed to a push-button activated signal in January 2004. As part of the streetscape redevelopment project, this intersection will be changed to a four-way signalized intersection.

An additional pedestrian signal will be installed at the intersection with N. 152nd Street. Currently this location has no signal or pedestrian crosswalk markings. Figure 9-3 illustrates the existing conditions south of the signalized intersection with N. 155th Street. The crossroad shown in the image on the right is N. 152nd Street. The proposed improvements are illustrated in the conceptual rendering in Figure 9-4.



Figure 9-3. Shoreline – Existing Conditions Near the Intersection with N. 152nd Street



Figure 9-4. Shoreline – Conceptual Rendering of the Intersection with N. 152nd Street

Part of the landscaped median analysis includes analyzing the effects of the medians and pedestrian environment improvements on pedestrian actions and safety. The initial phase of a pedestrian-crossing study was conducted south of the proposed new pedestrian signal at N. 152nd Street. Following the completion of construction, the *after* data will be collected and analyzed. These data will illustrate changes in pedestrian volumes as well as behaviors at the specified location.

One mid-block location between 152nd and 155th experienced 24 accidents within the three-year analysis period. This location is at the end of the TWLTL at the

northbound approach to N. 155th Street, as the lane changes to a dedicated left turn lane and a right turn lane is added. The TWLTL will be replaced by a median as part of the project, and a BAT lane will replace the right turn lane. With these changes, the number of accidents at this location is likely to decrease following the completion of the construction.

Fixed-Object Collisions

Within the Shoreline Aurora Avenue Phase 1 project area, 14 fixed-object collisions occurred in the *before* analysis period. The types of objects involved and the severities of the injuries sustained in these collisions are detailed in Table 9-4.

Table 9-4. Shoreline – Fixed-Object Accident Characteristics Before and After Project Construction

	Before	After*	
	14 crashes 16 fixed objects**	X crashes X fixed objects	
Fixed Objects	<ul style="list-style-type: none"> • Curb or island (2) • Wood sign post (2) • Guide post (1) • Luminaire pole (4) • Utility pole (3) • Traffic signal (1) • Tree or stump (1) • Fire plug (1) • Mail box (1) 	<ul style="list-style-type: none"> • 	
Severity of Fixed-Object Accidents	<ul style="list-style-type: none"> • Fatal (0) • Disable (0) • Evident Inj (5) • Possible Inj (1) • PDO (8) <p>Tree crash resulted in an evident injury</p>	<ul style="list-style-type: none"> • Fatal () • Disable () • Evident Inj () • Possible Inj () • PDO () 	

*After data for 2007-2009 will be available in 2010

**Note two crashes each involved two objects

The severity of the fixed-object collisions ranged from no injury to evident injuries. The overall severity of fixed-object collisions was high in comparison to other sections of SR 99, given that six of the fourteen resulted in injury.

A “fixed-object collision rate,” similar to the other accident rates, is calculated by using Equation 3. This rate describes fixed-object incidents in order to better compare this experience to other sections of SR 99.

For the *before* conditions along Shoreline's Phase 1 project, this calculation results in a value of 3.13 fixed-object collisions per 10 million vmt. This rate is high in comparison to other sections of SR 99 under redevelopment, exceeded only by SeaTac's phases 1 and 2 (which were 3.32 and 3.90 per 10 million vmt, respectively).

Fixed-object accidents were concentrated at intersections. Five occurred at the intersection with N. 160th Street, and three at N. 165th Street. Two of the accidents at each of these intersections involved drivers under the influence of alcohol. The two-car collision involving a tree occurred at the intersection with N. 145th Street; one of the vehicles turned at the intersection and struck the tree after colliding with the oncoming vehicle. One of those drivers was also under the influence of alcohol. Note also that this accident occurred before redevelopment and the planting of street trees along the sidewalk and within the median.

Injury Severity

The overall severity of the accidents within the Shoreline project area ranged from no injury (property damage only) to disabling injuries. The numbers of accidents resulting in each level of injury severity are listed in Table 9-5. The two disabling injury accidents involved one pedestrian and one two-car collision at a driveway.

Table 9-5. Shoreline – Injury Severities Before Project Construction

	Before	After*	
Fatal	0		
Disabling Injury	2		
Evident Injury	22		
Possible Injury	100		
Property Damage Only	213		
Total	337		

*After data for 2007-2009 will be available in 2010

The two disabling injuries accounted for 0.6 percent of all accidents, which is a smaller proportion than those found in other sections of SR 99. Likewise, it is lower than the statewide average of 3.0 percent or the Northwest Region average of 2.3 percent. Overall, this section of SR 99 had a lower incidence of severe-injury accidents within the

analysis timeframe. However, a longer history of this corridor indicates that this route has frequent severe-injury accidents.

Pedestrian and Bicyclist Accidents

This number included one bicyclist accident at the intersection with N. 165th Street and three pedestrian accidents. One pedestrian sustained a disabling injury at the intersection with N. 165th Street, and the other two pedestrian accidents were at mid-block locations and resulted in evident injuries to the pedestrians. As noted above, different pedestrian crossing features have been installed at locations along this corridor before the construction of this streetscape redevelopment project. In addition, a pedestrian crossing study is being conducted at an unsignalized mid-block location.

Speed Studies

Mid-block spot speed studies were conducted between 2001 and 2003, prior to redevelopment. The 85th percentile speeds recorded in these studies ranged from 40 to 47 mph. A 40 mph speed limit is posted along SR 99 through Shoreline. Data collected following the completion of this project will be used to determine any effect that the median and roadside changes have on corridor speeds.

Shoreline Conclusions

The accident rate along Shoreline's Phase 1 project was high in comparison to the statewide and regional rates for similarly classified facilities, as well as to rates for other sections of SR 99 prior to redevelopment. Likewise, the fixed-object rate was high in comparison to those of other sections of SR 99, as was the proportion of fixed-object accidents resulting in injury, although there were no disabling injuries or fatalities.

The Shoreline landscaping plan is unique in that it will cluster trees throughout the median, instead of planting them at equal intervals. This will provide an opportunity to compare the accident rates and travel behaviors through this corridor to those of project areas that have different landscaping plans.

One element that will aid in the evaluation of changes in travel behavior is the speeds at which individuals travel. The results of spot speed studies conducted following construction of the project will be compared to current speed studies. Given that the

speed limit is 40 mph and the 85th percentile speeds prior to redevelopment were between 40 and 47 mph, it will be interesting to note any change in travel speeds.

SHORELINE MODELING RESULTS

Modeling will be conducted after data become available in 2010.

CHAPTER 10

WSDOT REDEVELOPMENT

PROJECT DESCRIPTION

The WSDOT is designing streetscape, capacity, and safety improvements for a 0.83-mile-long section of SR 99 south of the Kent streetscape project and north of the Federal Way city limit. This section of SR 99 is within an unincorporated area of King County. The project will extend from S. 284th Street to S. 272nd Street, as illustrated in Figure 10-1.

WSDOT initiated this project to address the heavy congestion of the SR 99 route during rush hour as traffic moves from I-5 to SR 99 via S. 272nd Street. This project will also create a consistent highway cross-section along SR 99 south of SeaTac by installing BAT lanes in the north- and southbound directions that will replace the TWLTL with medians and dedicated left turn lanes, as well as roadside access control measures such as sidewalks and driveway definition and consolidation.

Other improvements along this corridor will include upgrading of bus zones, features to meet disability access needs, illumination throughout the corridor, roadside landscaping strips to improve pedestrian safety, and transit reliability improvements resulting from the installation of a signal priority system throughout the project area along with the BAT lanes. Environmental elements will also improve the local natural environment, and detention facilities will treat and detain highway runoff to eliminate harmful impacts.

The timeline for this project is that construction will begin in the summer of 2006 and will be completed within a year.



Figure 10-1. WSDOT – HOV Lane and Redevelopment Project Vicinity Map
(Source: http://www.wsdot.wa.gov/Projects/SR99/S284th_S272nd_HOV/map.htm)

DATA ANALYSIS

The *before* data for 2003 through 2005 will be available in mid-2006. Depending on the time line of construction completion, which is anticipated to conclude within 2007, the *after* data for 2008 through 2010 will be available in 2011.

SHORELINE MODELING RESULTS

Modeling will be conducted after data become available in 2011.

CHAPTER 11

KENMORE REDEVELOPMENT

PROJECT DESCRIPTION

In March of 2001, the city of Kenmore adopted its Comprehensive Plan, which includes a 20-year transportation plan that seeks to meet the needs of various users and stakeholders. The plan includes improvements to roadway, sidewalk, and transit facilities.

Bothell Way, the section of SR 522 that goes through downtown Kenmore, is an urban principle arterial. Currently, it experiences significant congestion, is in need of safety improvements, and is unattractive to many. The City of Kenmore is undertaking a two-phase project to address the safety, aesthetics, and operation of this route. Phase 1 will extend from 60th Avenue NE to 73rd Avenue NE, approximately mileposts 6.54 to 7.49. Phase 2 will extend from 73rd Avenue NE to the eastern city limit (mileposts 7.50 to 8.23). Construction of Phase 1 is anticipated to begin in 2006, with Phase 2 following within a year. Figures 11-1 and 11-2 illustrate the alignment of the Phase 1 and Phase 2 projects, respectively.

The existing facility is four to seven lanes, with two general-purpose lanes in each direction continuous throughout the corridor. The cross-section varies through the corridor, with a BAT lane in each direction at some locations, a center TWLTL at others, and turn lanes approaching intersections.

The major components of the improvement projects will include making alignment improvements at intersections; creating a Burk-Gilman Trail underpass; extending the BAT lanes to the eastern city limit; installing landscaped medians with a low-profile median barrier; and adding landscaping, street lighting, and sidewalks to several sections of the corridor. Two additional signals will be installed, one at the intersection with 83rd Place NE and one at the entrance to Kenmore Lanes. The bridge at Swamp Creek will also be replaced during Phase 2.

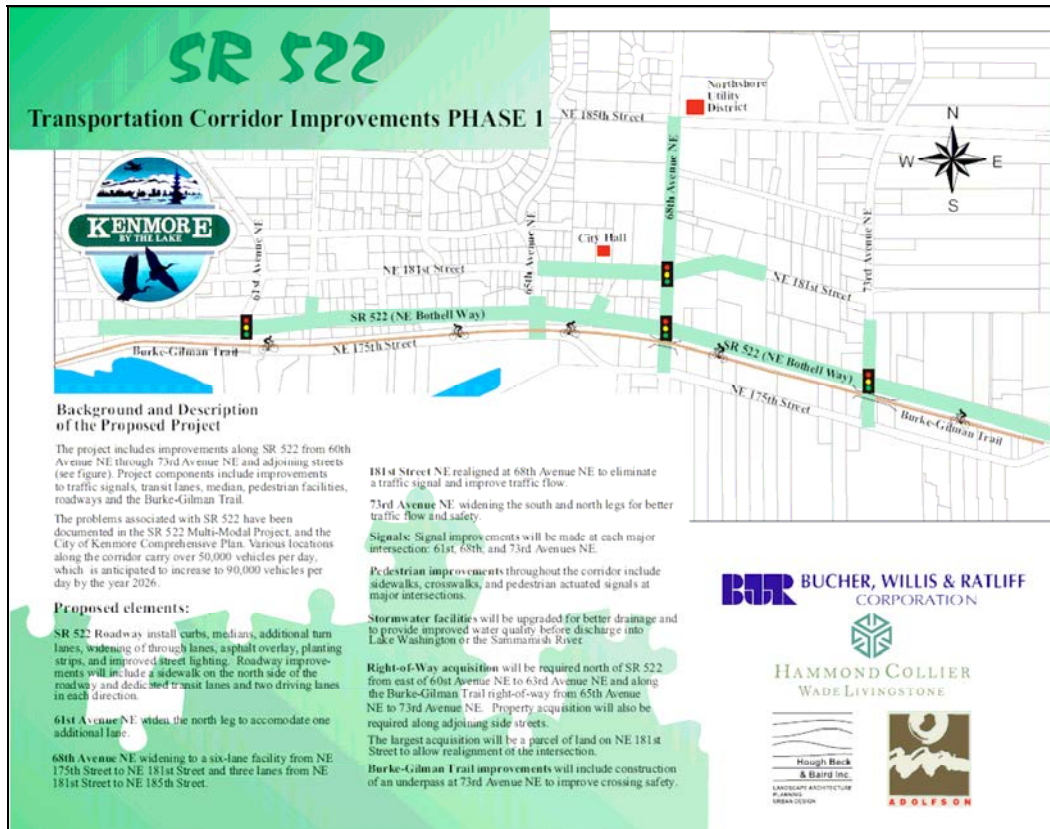


Figure 11-1. Kenmore Phase 1 – Streetscape Improvement Vicinity Map

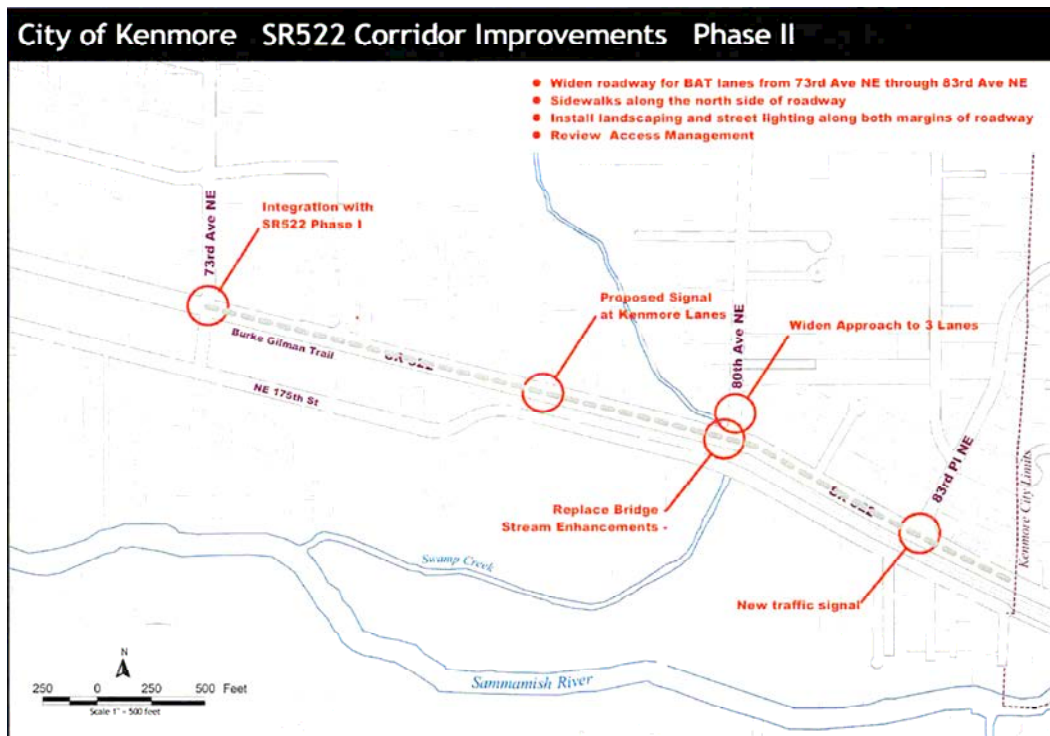


Figure 11-2. Kenmore Phase 2 – Streetscape Improvement Vicinity Map

The overall cost of this project is estimated at \$20 to \$25 million for Phase 1 and \$15 million for Phase 2. Partial funding has been secured from the City of Kenmore, the Transportation Improvement Board, federal grants (STP), WSDOT, King County, Kenmore Land Sale, and Sound Transit.

DATA ANALYSIS

Phase 1 Data Analysis

Before data for 2003 through 2005 will be available in mid-2006, and *after* data for 2009 through 2011 should be available in 2012, depending on the time line of construction completion.

Phase 2 Data Analysis

Before data for 2004 through 2006 will be available in mid-2007, and *after* data for 2009 through 2011 should be available in 2012, depending on the time line of construction completion.

KENORE MODELING RESULTS

Modeling will be conducted after data become available in 2012.

CHAPTER 12

MUKILTEO REDEVELOPMENT

PROJECT DESCRIPTION

The City of Mukilteo and WSDOT are collaborating on this project to widen SR 525, commonly known as the Mukilteo Speedway, and improve the safety and aesthetics of this urban corridor.

The section of SR 525 being widened runs west from I-5, past SR 99, to the City of Mukilteo. The route continues through downtown Mukilteo to the ferry dock and, via ferry, across Puget Sound to Whidbey Island. The roadside restoration project, which incorporates most of the aesthetic elements of interest to this research, runs from south of the un-signalized intersection with Evergreen Drive to north of the intersection with Paine Field Boulevard (a spur of SR 525 connecting to SR 526) approaching the downtown section of Mukilteo, as illustrated in Figure 12-1. The construction has been conducted in phases to minimize the impacts to travelers. Widening began in 2003 and was completed in 2004. Landscaping will continue through winter 2005.

The combined widening and roadside restoration projects are widening the route from two to four lanes, dividing the directions of travel with a landscaped median, adding sidewalks and bike lanes, and improving lighting and drainage. Provisions for U-turns at intersections and a few mid-block left turn lanes within the median will aid accessibility along the route.

SR 525 is used by residents, area businesses, commuters, and ferry traffic. Long delays from increasing congestion and multiple collisions raised awareness of the need for safety improvements; widening and dividing the roadway were critical steps toward increasing traffic flow and improving safety. New sidewalks and bike lanes will address the safety and accessibility of non-motorized users, and new street lighting will improve nighttime visibility.

The median landscaping will consist of low-growing vegetation and trees. At locations where trees will be planted, the median will have a low-profile barrier to mitigate the potential impacts of placing trees within the design clear zone. Other sections

of the median without trees will have a standard 6-in. curb. Roadside trees will also be planted along many segments of the project area within a landscaping strip between the roadway and the sidewalk.

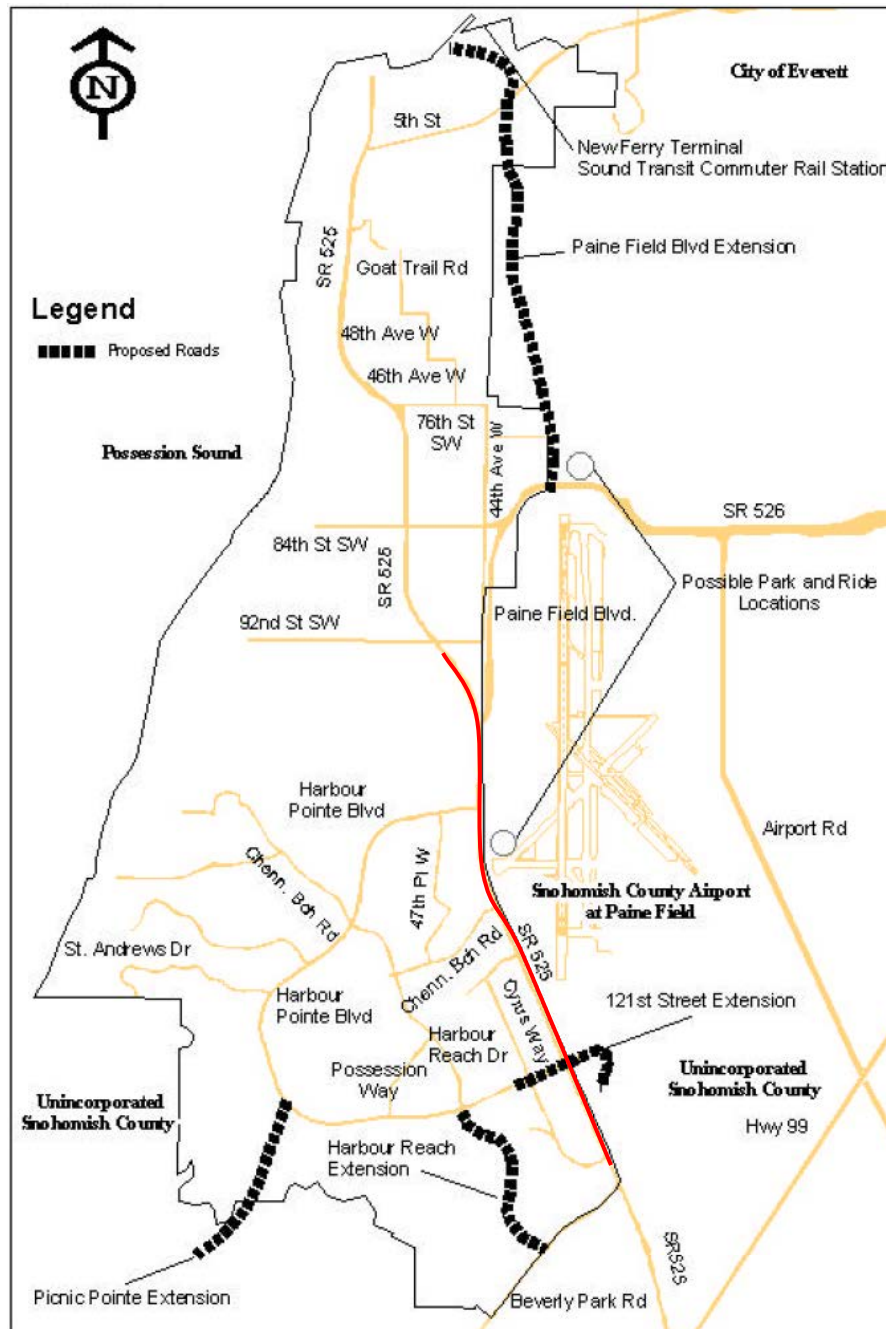


Figure 12-1. Mukilteo – Mukilteo Speedway Roadside Restoration Project Vicinity Map
(Source: <http://www.ci.mukilteo.wa.us/cityinfo/city-info.htm>)

DATA ANALYSIS

The roadway environment changed significantly during project construction, leading to expectations that accident occurrences will also change. Controlled access changed where vehicles enter and egress adjacent property, which is likely to change the locations of accidents. Different types of fixed objects are in the roadside environment: *before* conditions included utility poles and other highway facility hardware, whereas after development, trees, luminaire poles, and signal hardware are more prevalent. This analysis consists of evaluating the “before” conditions in terms of number, type, location, and severities of accidents. Accident rates based on traffic volumes are also presented. The speed studies discussed will be used to evaluate the effects that the redevelopment has on driving characteristics.

Accident Types

Before construction of Mukilteo’s project (in the data collection period between 2000 and 2002) 291 accidents occurred along the 2.22-mile section. Two accidents involved bicyclists, and one pedestrian was involved in an accident. There were no fatal accidents. Ten vehicle drivers were under the influence of alcohol. These general statistics are presented in Table 12-1.

Table 12-1. Mukilteo - Basic Accident Characteristics Before Project Construction

	Total Accidents	Fatal	Bikes	Peds	DUI	
Before	291	0	2	1	10	
After*						

3 years of data collected for *before* analysis

Section length = 2.22 miles

**After* data for 2005-2007 will be available in 2008

The bicyclist accidents occurred at a mid-block location and the intersection with Paine Field Boulevard, and the bicyclists were evidently injured. The pedestrian received a disabling injury after being struck at a mid-block shopping center driveway. Another disabling injury resulted from a rear-end accident in which one driver was under the influence of alcohol, and a third disabling injury was caused by an opposite-direction

accident. Both occurred at intersections (Harbour Point Boulevard North and Paine Field Boulevard, respectively).

The predominant types of accidents within the project area before construction that accounted for approximately 10 percent or more of the total accident experience (as listed in Table 12-2) included rear-end accidents (54 percent), driveway-related (14 percent), and left turns (11 percent). These accident types are similar to those that occurred within other SR 99 projects prior to redevelopment. The proportion of rear-end accidents exceeded that of most of the other projects in this analysis; although Kent and SeaTac's Phase 3 experienced 54 percent and 52 percent rear-end accidents, respectively, the typical values ranged from 33 to 47 percent. Therefore, reducing rear-end accidents was listed as one of the main objectives of widening the roadway and providing left turn lanes.

Table 12-2. Mukilteo – Predominant Accident Types Occurring Before Project Construction

	Rear End	Driveway Related	Left Turns	
Before	54.0%	13.7%	10.7%	
After*				

3 years of data collected for *before* analysis

**After* data for 2005-2007 will be available in 2008

Accident Rates

Average daily traffic values between 1999 and 2001 (prior to project construction) varied from 14,000 to 34,000 vehicles per da (vpd), averaging 24,300 vpd along the project section. The accident rate, calculated with Equation 1, results in a value of 4.92 accidents per million vehicle miles of travel (vmt). There were no fatal accidents within the analysis timeframe; therefore, the fatal accident rate is zero.

In comparison to other sections of SR 99, this value falls in the midrange of other *before* accident rates, which generally ranged from 3.5 to 8 per million vmt. However, the 1996 statewide average accident rate for highway facilities classified as Urban Principle Arterials was 2.97 per million vmt. SR 525 is within WSDOT's Northwest Region, and the average accident rate for all facilities in this region was 2.12 per million vmt. Likewise, within Snohomish County, the accident rate was 1.97 per million vmt. From

this it can be concluded that the overall accident rate along this section of SR 525 was higher than those on similarly classified routes and within the WSDOT region and county for the analysis timeframe.

Accident Locations

There were three signalized intersections within the project section prior to construction. A total of 63 percent of all accidents along the section occurred at intersections, as listed in Table 12-3.

Table 12-3. Mukilteo – Intersection and Driveway Accident Characteristics Before Project Construction

	Inter- sections	Drive- ways	Mid Block	Ever- green	121 st St SW	Harbour Pt S	Chinault Beach Dr	Harbour Pt N	Paine Field	
Before	3~63.0%	14.3%	19.3%	30	13	37	14	27	12	
After*	4**									

3 years of data collected for *before* analysis

**After* data for 2005-2007 will be available in 2008.

**One additional intersection will be installed in the course of this construction project

This project is making numerous modifications to these intersections:

1. The un-signalized T-intersections with Evergreen Drive and Russell Road (at milepost 4.60) will have median islands and dedicated turn lanes. The movements that will be allowed at these locations include northbound traffic turning left onto the side streets, and traffic turning left and merging into northbound SR 525 traffic.
2. Additional locations will have dedicated mid-block left-turn pockets. Median curbs will preclude southbound traffic from accessing 121st Street SW at the T-intersection.
3. An additional signal will be installed between Harbour Point Boulevard South and Chinault Beach Drive. This mid-block location, which experienced 11 accidents prior to redevelopment, will provide access to a shopping center (MP 4.29).
4. The merge/diverge style intersection with Paine Field Boulevard will allow unrestricted northbound right-diverging and right-merge movements. Northbound and southbound through-movements and left turns from Paine

Field Blvd will be signal controlled. Southbound left turn movements to Paine Field Blvd will not be allowed. It is currently a three-way intersection, but a fourth leg (approaching from the west) will be added.

Fixed-Object Collisions

Within the three years before construction of this project, 12 fixed-object collisions occurred, as listed in Table 12-4.

Table 12-4. Mukilteo – Fixed-Object Accident Characteristics Before Project Construction

	Before	After	
	11 crashes 11 fixed objects	X crashes X fixed objects	
Fixed Objects	<ul style="list-style-type: none"> • Curb or island (1) • Utility pole (1) • Guardrail end (1) • Concrete barrier end (1) • Earth bank (1) • Fire plug (1) • Fence (2) • Roadway ditch (3) 	<ul style="list-style-type: none"> • 	
Severity of Fixed-Object Accidents	<ul style="list-style-type: none"> • Fatal (0) • Disable (0) • Evident Inj (0) • Possible Inj (2) • PDO (9) 	<ul style="list-style-type: none"> • Fatal () • Disable () • Evident Inj () • Possible Inj () • PDO () 	

Nine of these accidents resulted in no injuries to the individuals involved. Two of the drivers possibly sustained minor injuries. This severity level was significantly lower than those on most of the SR 99 project sections. The frequency was also lower, with a fixed-object collision rate of 0.19 per 10 million vmt (calculated with Equation 3). The fixed-object collision rates of most other SR 99 sections before construction fell between 1 and 4 per 10 million vmt.

Injury Severity

Table 12-5 lists the level of injuries for all collisions within the project area during the three-year analysis period.

Table 12-5. Mukilteo – Injury Severities Before Project Construction

	Before	After*	
Fatal	0		
Disabling Injury	3		
Evident Injury	26		
Possible Injury	84		
Property Damage Only	178		
Total	291		

*After data for 2005-2007 will be available in 2008

Disabling accidents accounted for 1.0 percent of all accidents. In 1996, disabling injuries within the Northwest Region accounted for 2.3 percent and statewide for 3.0 percent. This indicates that the rate of most severe injuries was below other comparable proportions, even though the overall accident rate (indicating total frequency) was higher. Similarly, the evident injury level accounted for 8.9 percent of all accidents in comparison to 12.2 percent within the Northwest Region and 13.7 percent statewide.

Pedestrian and Bicyclist Accidents

In total, there were two bicyclist accidents, which occurred at a mid-block location and at the intersection with Paine Field Boulevard and which both resulted in evident injuries to the bicyclists. There was also one pedestrian accident, which resulted in a disabling injury after the pedestrian was struck at a mid-block shopping center driveway. These incidents represent a lower rate of incidents with pedestrians and bicyclists than the rate along other SR 99 sections under redevelopment. Given that pedestrian volumes along these routes were not available for the analyses timeframes, we cannot adequately quantify the safety or the effectiveness of any non-motorized user facilities.

Speed Studies

The posted speed limit changes from 60 mph to 40 mph approaching the project section from the south. This 40 mph speed limit is maintained throughout the project area before further reducing to 35 mph within the downtown area. Speed studies were conducted to record the pre- and post-construction speeds of travelers on SR 525 near the

City of Mukilteo. The speed studies before project construction recorded 85th percentile speeds between 45 and 47 mph at various mid-block sections in 1999. Following construction, spot speed studies recorded 85th percentile speeds of 45 to 48 mph in 2005. Further investigation into the distribution of speeds recorded in these studies may illuminate any differences in travel behavior that may be attributable to the change in roadway environment.

Mukilteo Conclusions

The overall accident rate of 4.92 indicates that this project area experienced a significantly higher rate of accidents than similarly classified facilities within Washington State. This is not surprising, given that one of the objectives of the project is to improve safety. In addition, the frequency of rear-end accidents was high in comparison to other SR 99 project sections. However, although accident frequencies were high, the accident severities experienced within this project area prior to construction were low in comparison to accident severities within the Northwest Region and statewide.

The project results will be analyzed when the *after* data are available in 2008.

MUKILTEO MODELING RESULTS

Modeling will be conducted after data become available in 2008.

CHAPTER 13

CONCLUSIONS AND FUTURE RESEARCH

This report has presented accident rates and experiences before and after the construction of two streetscape redevelopment projects in SeaTac, Washington, as well as accident rates and experiences before the construction of two additional SeaTac projects, other SR 99 projects within Des Moines, Federal Way, Shoreline, and Kent, and a project on SR 525 through Mukilteo. The beginnings of two other landscape projects are discussed, one along SR 522 in Kenmore and one in unincorporated King County. The intent of this analysis is to quantify the safety of state routes 99, 522, and 525 to determine whether features added to improve roadway aesthetics and the quality of life of those who live and work on or near these urban corridors have any significant negative impacts on the safety of road users.

Road safety is a “better” or “worse” measurement, not an absolute. Therefore, the analyses are based on several types of comparisons. First, for each project, conditions before and after construction are compared. Each project is also compared to the others being analyzed. Changes in individual measures of safety (e.g., pedestrian safety, intersection safety, fixed object collisions) are likewise noted. Finally, accident rates, types, and severity levels are compared with those on similarly classified highway facilities in Washington State.

CONCLUSIONS

As of this writing, most projects selected for analysis had only been recently finished or were still under construction, so *after* data for comparison and analysis of these projects will not be available for several years. Only two analyses have been completed thus far: those for phases 1 and 2 in SeaTac.

The SeaTac phases 1 and 2 analyses showed that, initially, SR 99 was a high-accident corridor in comparison to other similarly classified highway facilities in Washington State. Following the construction of the Phase 1 and Phase 2 streetscape projects, SR 99 is still a high-accident corridor. The accident rate for the combined SeaTac phases 1 and 2 projects decreased; however, there is little other evidence to

suggest an improvement in the overall safety within these project areas. In fact, an increase in the accident rate for the Phase 2 project shows that the results based on the frequency of accidents were mixed.

Overall, the locations of accidents shifted significantly within the SeaTac phases 1 and 2 projects. Before the projects were constructed, more accidents occurred at mid-block locations than following construction. This result was expected, given the extent of turning movement restrictions imposed by installed medians. On the other hand, U-turn accidents increased following the projects' construction, increasing from four accidents to 35 within three years. These changes relate directly to the access control effects of the medians.

The accident frequency models indicated that prior to redevelopment, geometric factors such as wide shoulders, access control, and curbs separating lanes tended to reduce the frequency of accidents, whereas bus stops, some turn lanes, intersections, and horizontal curves tended to increase the number of accidents. Following the construction of these projects, the most significant factors contributing to increased accident frequencies were similar; however, notable differences were that some access control measures tended to increase accidents, and the total number of trees within a section of the highway decreased accident frequency. Some might interpret the finding of reduced accidents as an indication that trees provide a "traffic calming" effect. However, given the structure of the data and the locations of the trees (specifically, more trees are within sections that have the least potential for conflicting traffic movements and potential accidents), we can not conclude that trees provide a specific safety benefit when planted within medians and in close proximity to the roadside. In addition, the variable for trees along the east roadside showed a positive association with the frequency of trees in the model excluding intersection accidents, indicating that with more trees there are likely to be more accidents. This may be related to obscured visibility at driveways and to the number of access points along the east side of SR 99 (which is significantly greater than along the west side). Most of the trees struck during the analysis timeframe were within narrow (5 feet or less) medians. Following the construction of these first two projects, SeaTac revised its planting plans to exclude trees within narrow medians on the basis of

its accident experience with trees in these locations. Therefore, this effect may not be significant in analysis of subsequent projects.

The tree incident records indicated that vehicles collided with more than the eight trees reported in the collision records. A total of 32 trees were replaced in the three-year analysis period as a result of vehicle strikes. When these incidents were included in the “fixed-object collision rate,” the rate increase from the *before* to the *after* conditions was significant. Early reports of tree collisions do not involve high severity injuries. Future investigation will likely continue to investigate the impacts of tree growth on collision severity.

The severity models indicated that trees contribute to a higher probability of property damage accidents. These models also showed that the probability of sustaining an injury increased after redevelopment. However, this change was not shown to be statistically significant.

Additional measures of safety relate to specific types of accidents. Pedestrian and bicyclist safety remains a high priority, as an important goal of the streetscape redevelopment plans is to improve the livability and “walk-ability” of the road and roadside environment. The SeaTac analyses indicated that the number of bicyclists struck in vehicular accidents decreased following construction of the phases 1 and 2 projects. Likewise, pedestrian accidents decreased in frequency, although the severity of the accidents following construction of both phases was higher. Given the low number of accidents involving bicyclists and pedestrians, we cannot determine whether this change is statistically significant. A sidewalk impact study was conducted along the Phase 2 project area (Knoblauch 1998). This study measured the volume and activity of pedestrians in 1997 and 1998 (immediately before and after project construction). The results indicated a 15 percent increase in pedestrian volume, although it showed that this increase was not statistically significant. These data were not within the analysis timeframe established for this current analysis; however, they indicate that pedestrian usage along the SR 99 corridor did not significantly increase immediately following the Phase 2 project’s construction. *Before* and *after* volumes of bicyclists were not available. Overall, pedestrian and bicyclist accident experiences are difficult to compare to

determine any changes in safety, although there does appear to be some need for additional pedestrian safety measures.

The *Bus Stop* indicator in the frequency and severity models was significant for the *before* conditions but insignificant following redevelopment. This indicates some degree of safety improvements at bus stops. The locations, characteristics, and visibility of bus stops were improved as part of these projects; improvements included moving most of them to the far side of intersections and constructing pullouts for transit vehicles.

The findings indicated that trees affected the safety of the roadway, contributing to increased accident frequencies and the number of property-damage-type accidents. Given the predicted accident frequencies and the actual number of tree replacements not reported as accidents (identified in maintenance records as being struck by a vehicle) combined with long-term tree diameter growth and increased rigidity, the effects of planting trees within the Design Clear Zone (DCZ) (see Appendix A) along an urban principle arterial warrant continued study.

The different measures of safety on SR 99 indicated some improvements for specific user groups and locations. However, the decrease in the overall accident rate and the shift in accident severities (indicating an increased probability of injury) were not shown to be statistically significant. Therefore, the effects of this type of streetscape redevelopment project cannot yet be concluded. Additional research will likely lead to a more complete understanding of the impacts of aesthetic design features and street trees installed as part of a streetscape redevelopment project within a high-speed urban corridor.

FUTURE RESEARCH

The current data set may be used to develop additional models and could be modified to investigate accident frequencies defined by the direction of travel. This would isolate some of the effects of access control from the effects of trees by identifying the side of the road on which an accident occurred.

Difficulties arose with some variables in the current data set in the statistical analyses of SeaTac because the variables were essentially constant, especially after construction. The In-Service Evaluation of Major Urban Arterials with Landscaped Medians will extend at least an additional five years, to 2010, to collect data from other

cities that are implementing similar streetscape redevelopment projects. Collecting data from these project areas is likely to increase the variation in some variables (such as number of lanes, median type, and frequency/spacing of trees), which may shed light on additional effects of and interactions among variables. Varied median designs and features will allow comparisons of the safety impacts of these designs, leading to a better understanding of what elements are more safe within this high-speed urban corridor context.

Determining the long-term impacts of trees within the DCZ on an urban principle arterial remains a high priority. SeaTac's phases 1 and 2 projects were completed close to 10 years ago, so additional data are now available that may illustrate the longer-term impacts of trees and of the streetscape redevelopment projects. The current study did not undertake to analyze these data because 1) the standardized framework for the In-Service Evaluation of Major Urban Arterials with Landscaped Medians assumed a three-year analysis timeframe and 2) serial correlation issues based on multiple accident counts at the same location (one count per year) may increase with the increased number of years. Modeling techniques such as negative multinomial and three-stage least squares may be investigated when data have potential serial correlation issues.

It may also be worthwhile to document the diameters of trees within all projects to determine the effects of large trees in comparison to smaller ones. This is likely to illustrate the long-term effects of planting trees within the DCZ. Such measurement is not possible retroactively but should be considered for some of the projects that are just reaching the end of their construction phase. Annual tree diameter measurements would be preferable.

Additional research that investigated a streetscape redevelopment project with fewer changes to the infrastructure would isolate the effects of landscaping from the effects of access control and other geometric changes that affected the outcomes in the current study. Ideally, such a study would entail an existing four- to six-lane divided highway with medians, mid-block turn pockets, and sidewalks so that the project would simply install landscaping within the median and along the roadside.

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APPENDIX A LITERATURE REVIEW

The intent of this literature review is to provide a brief review of existing design guidelines for and impacts of landscaped medians from other state and local agencies to provide a better basis for future decisions. Although the in-service evaluation mainly targeted urban landscaped medians with trees and shrubbery, broader aspects of urban roadway design were explored in support of project development. This review provides lessons learned about factors that should be considered in determining how median trees can be used to beautify roadway landscape without compromising roadway safety.

GENERAL STATE OF PRACTICE

The literature search found few accident studies and statistics involving medians with trees on urban arterials, that is, whether landscape enhancement has a causal effect on accident frequency or severity. While the American Association of State Highway and Transportation Officials (AASHTO) does provide general guidance about the effects of the location and size of trees and shrubs on visibility, no definitive set of guidelines for appropriate landscaped median treatments is available. The lack of specific AASHTO guidelines in median aesthetic design suggests variability in practice among state and local agencies.

Lack of Specific AASHTO Guidelines

As indicated in the 2001 AASHTO *Policy on Geometric Design of Streets and Highways* (frequently called the Green Book), medians are a desirable feature of arterial streets and should be provided where space permits. Besides separating opposing traffic, medians in urban areas can offer an open green space, may provide a refuge area for pedestrians crossing the street, and may control the location of intersection traffic conflicts. Median trees provide vertical definition, enhance aesthetics, provide environmental benefits, and may smooth traffic flow. However, the Green Book does not specify how to treat trees in medians other than “plantings and other landscaping features in median areas may constitute roadside obstacles and should be consistent with the AASHTO *Roadside Design Guide*.”

The AASHTO *Roadside Design Guide* (2002), often referred to as the best practice reference, indicates that trees become potential obstructions by virtue of their size and their location in relation to vehicular traffic. Most often, designers must deal with existing trees that may present an obstruction to errant motorists. The design guide focuses mostly on methods to treat “existing” conditions, such as how to keep the motorist on the road (i.e., pavement markings) and how to mitigate the danger inherent in leaving a roadway that has trees beside it (i.e., tree removal). With regard to new plantings, no detailed guidelines are provided. The Guide states that when new landscaping is designed, the most important factor is how the location and mature size of trees and shrubs affect visibility. Trees can be hazardous if poor decisions are made about their size, type, and location and if they are not well maintained. For example, if planted inappropriately, they may create a driving hazard by obscuring vision. They may also block sunlight from reaching snow- or ice-covered pavements. Large trees,¹ typically over 40 feet tall, should not be placed at decision points (i.e., island noses).

Variability in Median Aesthetic Designs

Practice regarding the aesthetic designs of medians varies from state to state, as well as between municipalities. There is no universal set of factors that can be used to determine the need to install medians. According to a state-of-the-practice survey included in National Cooperative Highway Research Program (NCHRP) Synthesis 299 (2005), states usually rely on accident history, design speed, traffic volumes, numbers and locations of driveways, type of access control, and cost, while larger cities rely on traffic volumes, available right-of-way, and street classification.

Some believe that a strict rule or policy is not necessary because many exceptions are likely to occur as a result of site conditions, political decisions, and citizen requests; others, however, try to follow a set of guidelines to maintain consistency. Nevertheless, all have the same goal: to provide a safe, aesthetically pleasing, and cost-effective design. While guidelines from AASHTO are well recognized, conditions and concerns often vary greatly from site to site, and often so significantly that using standard approaches does not appear to be the most effective process. Therefore, practice with landscaped medians

¹ A large tree is typically over 40 feet tall. Medium trees range from 25 feet to 40 feet tall. Small trees are from 5 feet to 25 feet tall. Both large and medium trees are at least 8 feet tall with a 1.5-foot trunk diameter when planted.

varies on the basis of agencies' experiences, safety regulations, and engineering judgment.

CONTEXT SENSITIVE DESIGNS

Recent national transportation project development trends have focused on developing facilities that are seamlessly incorporated into their environmental and social context. These principles have been termed Context Sensitive Designs/ Context Sensitive Solutions (CSD/CSS). Some of the leading agencies involved in the early development of these principles include the transportation departments from Connecticut, Kentucky, Maryland, Minnesota, Utah, and Washington. The Federal Highway Administration (FHWA) has also been a leader in bringing these principles to the forefront of research and implementation.

At the national level, the FHWA, AASHTO, and NCHRP have each published documents and reports discussing the development and implementation of context-sensitive designs. *Flexibility in Highway Design* (FHWA 1997), *A Guide to Best Practices for Achieving Context-Sensitive Designs* (NCHRP 480 2002), and *A Guide for Achieving Flexibility in Highway Design* (AASHTO 2004) address the importance of context, discuss the implications of deviating from existing design standards, and inform decisions regarding flexibility in highway design. None of these documents serve as “standards” or regulations themselves; instead, they highlight the areas in which flexibility already exists in design standards and encourage designers to use their judgment in developing creative, safe, and attractive project solutions.

The Washington State Department of Transportation (WSDOT) has initiated numerous activities to incorporate these principles into the way it conducts business. The vision for transportation within Washington State developed by the Washington State Transportation Commission directs WSDOT “to develop projects in rural and urban areas by working with its partners to foster multimodal transportation systems that enhance communities and to develop collaborative transportation actions sensitive to community values.” (Milton 2005, p. 1)

In 2003, WSDOT published the Context Sensitive Solutions Executive Order (WSDOT E 1028.00) concerning implementation of CSD/CSS principles. It states that WSDOT endorses the CSD approach for large and small projects, from early planning

through construction and operation. The aesthetic, social, economic, and environmental values, needs, constraints, and opportunities of the broad community setting are all considered during the development of transportation projects, in addition to the functional objectives of the facility.

WSDOT has also developed guidelines that address CSD/CSS in its document titled *Understanding Flexibility in Transportation Design – Washington* (Milton and St. Martin 2005). This report details the considerations that communities, project planners, and engineers face when they address a wide variety of transportation facility development issues, including streetscape redevelopment projects. It does not present rigid standards but provides information about the tradeoffs to be made and the differing perspectives of stakeholders. Scientific evidence related to potential tradeoffs is presented if it exists. The topics relating to trees within urban contexts (such as environmental and social benefits, and potential safety impacts when planted in the Design Clear Zone) are addressed (pp. II-2.4 and IV-1.1 – IV-1.10).

SAFETY AND AESTHETICS

Trees are often requested by cities to increase the livability of the downtown environment. Research by Sullivan and Kuo (1996), Wolf (2003, 2004), Ulrich (1986), and Xiao et al. (2000) showed that the aesthetic, social, and environmental benefits of roadside trees, such as shade, vertical definition for the streetscape, enhancement of economic vitality, and stormwater runoff infiltration, are significant. However, little research has investigated the safety impacts within urban contexts.

Roadside Fixed-Object Collisions

Roadside fixed objects in urban areas may include landscaping (e.g., trees with a trunk diameter greater than 4 in.), utility poles, non-breakaway street light poles, fire hydrants, and traffic control devices. All of these could be in the path of a vehicle leaving the roadway. A number of studies have indicated that run-off-roadway collision rates are affected by the geometry and roadside elements of the roadway, such as horizontal curves (Fink and Krammes 1995), lane and shoulder widths (Zegeer et al. 1981), traffic volume (Zhou and Sisiopiku 1997), and median width (Knuiman et al. 1993). From this we conclude that to better understand the relationship between roadway safety and collision

rate and severity, it is necessary to take into account the geometric characteristics of the segments studied.

While many studies have investigated the effects of fixed roadside elements on collisions—for example, the association of wood utility poles with significantly higher severities than other types of utility poles, the effects of collisions with sign supports, and the effects of luminaire poles on vehicle impacts (Lee and Mannering 1999 and 2000)—very few studies have looked at the impacts of urban roadside designs that include fixed aesthetic elements. NCHRP Project 17-18(3) reported that trees are commonly struck in run-off-road collisions with severe impacts (Pfefer and Slack 2005).

Urban Trees

Rosenblatt and Bahar's research (1997) showed a decrease in mid-block accident frequency and severity following landscape enhancements. However, the report stated "it is unknown at this stage whether the landscape enhancements resulted in reduced speeds or a change in driver expectations regarding the nature of the road's character." A study by Turner and Mansfield (1990) provided insights about the characteristics of urban tree accidents. Their findings included the following:

- Urban tree accidents were less severe than rural tree collision patterns.
- Four times as many of the 164 tree accidents studied occurred on the outside of curves as on the inside.
- Very few small trees were reported to be involved in accidents.
- About 80 percent of the urban collisions were found to occur within 20 feet of the pavement edge.
- About 50 percent of the urban accidents were within 30 feet of the pavement on the outside of a horizontal curve.
- Collisions with trees whose trunks were 6 in. or wider in diameter were more severe than accidents with smaller diameter trees.
- In the absence of other factors, clearing trees within 10 feet of the pavement would probably reduce accidents by 40 percent.

Bratton and Wolf (2005) at the University of Washington College of Forestry Resources conducted research investigating the frequency and severity of crashes

involving trees. The research explored the relationship between urban tree accidents and severities in particular. The summarized conclusions drawn from the analysis were as follows:

- Collisions with trees are more harmful than other types of accidents.
- Accidents in rural areas are more frequent and more harmful than accidents in urban areas.
- Collisions with fixed objects are more frequent in rural areas than in urban areas.

They also noted that “there is no significant difference between urban and rural areas in relative collision incidence of cars striking trees (1.1% vs. 0.7%)” although the difference between mean speeds for collisions in which drivers strike trees (48 mph) and the mean speed for all other accidents (34 mph) is significant ($t = 23.94$, $p < .01$).

Speeds within many urban areas are less than 50 mph. Given the correlation between higher speeds and higher injury severities, the mean speed of collisions with trees in urban areas can be expected to be lower than the 48 mph reported by Bratton and Wolf. Therefore, the collisions with trees in urban contexts may result in lower levels of injury than the accidents occurring with trees in all locations.

Landscaped Medians

A study conducted by Cal Poly State University for the California Department of Transportation (Sullivan 2004) examined accidents on urban arterials with medians. Phase III of the study developed accident prediction models, based on cross-sectional data, for the frequency and severity of accidents. The data comprised nineteen sections with treed medians and ten with tree-less medians. The cross-sectional approach showed differences in accident rates along arterials with treed median and tree-less medians. The results showed that at the 95 percent confidence level, medians with trees were associated with an increased number of collisions when the collision analysis excluded crashes involving the right hand side of the road (thus excluding any influence or impact of sidewalk trees). The studies showed that increasing the median width did not reduce the crash rate, and that the effects of speed were mixed. The association between accident severity and tree presence was significant when crashes in the median lane and median

were analyzed. This association held true for 35 to 45-mph facilities with varied median widths, and whether or not intersections were included. The report concluded, “some association does exist between left-side collisions and median trees” (p. 10). There was also evidence that the number and severity of collisions declined with reduced travel speeds.

DESIGN STANDARDS

Some of the tasks involved in the Context-Sensitive Design process include defining and evaluating the tradeoffs within the specific project. Deviating from design standards has consequences that must be carefully considered. And yet, in many contexts innovative designs may be equally safe, or even safer, when the treatments are designed with the real needs and appropriate expectations of the users in mind. The most pertinent design standards considered in landscaped median projects are the clear zone and sight-distance standards.

Clear Zone

The WSDOT *Design Manual* defines the clear zone as “the total roadside border area, starting at the edge of the traveled way” (2005, p. 700-1). This is the actual value at the project location, while the Design Clear Zone (DCZ) is the target value. Specifically, the DCZ is the minimum desirable distance from the edge of the roadway to an unprotected fixed object greater than 4 inches in diameter (or any other roadside hazard such as a body of water). This distance depends on the facility’s speed, traffic volume, and the steepness of the roadside slope. The values are defined in Figure 700-1: Design Clear Zone Distances for State Highways Outside Incorporated Cities of the *Design Manual*. For example, the standard is 10 feet for 35 mph and lower; for cut sections and traffic volumes exceeding 6000 vehicles per day, the standards are 15 feet for 40 mph and 17 feet for 45 mph speed limits (WSDOT 2005, p. 700-10). This standard is supported by extensive research that has correlated the speeds of vehicles and the distance to fixed objects, with the severity of collisions. The desire for street trees is often disregarded because of conflicts with this DCZ standard.

As indicated in the 2001 AASHTO Green Book, in all cases an operational offset of 1.5 feet between the curb face and an object should be provided on urban arterials (p.

323). Although this value is cited as a minimum distance, is the Green Book clearly states that this is not a clear zone. A 3-foot clearance to roadside objects should be provided, particularly near turning radii at intersections and driveways. The *Roadside Design Guide* suggests 6.5 feet to 10 feet for large trees, although it concedes that “Figure 3.1 and Table 3.1 only provide a general approximation of the needed clear-zone distances...The designer must keep in mind site-specific conditions, design speeds, rural versus urban locations, and practicality” (2002, p. 3-2).

The North Carolina DOT selects clearance zones by using both the speed limit and the size of the tree. For speeds of less than 35 mph, a clear zone of 5 feet is used for small trees and 10 feet for large trees. For speeds between 35 to 40 mph, the distance has to be at least 8 feet from small trees and 15 feet from large trees. These clear zones are applied to both the outside of the roadway and within medians (NC DOT, No Date). The Texas DOT generally requires a 30-foot side clearance for plants 4 inches in diameter or larger, and 15 feet for plants smaller than 4 inches in diameter.

The *Florida Highway Landscape Guide* provides detailed information on the placement of trees and palms within medians and along the roadside (Lott and Graham 1995). The Florida standard for horizontal clearance on urban divided roads is 12 feet for the roadside clear zone. Curbed medians are allowed on roads with speeds of less than 50 mph. The minimum median width in which trees are allowed is 15 feet. The offset to a tree within the median must be at least 6 feet. Objects with a diameter greater than 4 in. are not permitted within this area, unless they are planted behind an approved traffic barrier such as a guardrail.

Clear zone requirements can affect other design decisions. For instance, the city of Redmond, Washington, prefers to use a vertical curb but does not want to provide shy distance to this curb by narrowing the median. Instead, it has installed a mountable curb, which does not require shy distance.

Barriers

Barriers are discussed in section 710 of WSDOT’s *Design Manual* (2000). This section indicates that the preferred methods of mitigating the impacts of fixed objects or other roadside hazards (e.g., bodies of water, embankments) that are within the Design Clear Zone (DCZ) are (in the order of preference listed on page 700-5)

- 1) removal
- 2) relocation
- 3) reduce impact severity (using a breakaway feature)
- 4) shielding.

Aesthetic features desired within the urban context, such as sidewalk and median trees and decorative elements, are generally located within the DCZ and obviously will not be removed, relocated, or made crashworthy (though some illumination standards and decorative objects are designed to break away upon impact). The shielding option remains.

Where fixed objects are desired within the DCZ for their aesthetic properties, shielding the objects with traffic barriers mitigates the effects of their presence. In current practice, barriers are used if the result of a vehicle striking the barrier will be less severe than the consequences that would result if no barrier existed. Median barriers may be used to mitigate the effects of hazards such as fixed objects within the median. Roadside barrier warrants are recommended on the basis of site-specific circumstances (Table 5.1 in *Roadside Design Guide*), but only for high-speed, controlled-access roadways. The input criteria used as the basis for median barrier warrants in the Guide (based on average daily traffic and median widths) are written for high-speed, controlled-access roadways. The Guide also says that for median barriers used on high-volume, non-access controlled facilities, caution should be taken to safely terminate such barriers and maintain appropriate sight distance at intersections.

Turner and Mansfield's 1990 study suggested that, whenever practical, new trees should be planted behind ditches, retaining walls, and other barriers. Roadside and median barriers should only be used to shield street trees when the likely severity of striking a tree is greater than that of striking the barrier. The Green Book states that a median barrier may be desirable on some arterial streets with fast-moving traffic. The *Roadside Design Guide* states, "the use of standard highway median barriers on urban facilities with a design speed of 44 mph or less with street intersections, regardless of access control, generally is not warranted."

In response to the desire for more aesthetically pleasing safety treatments within the urban environment, WSDOT has conducted crash tests on a number of innovative

median designs in accordance with procedures recommended in NCHRP 350 (Ross et al. 1993). Varying earth berm treatments were evaluated in these tests. A three-dimensional simulation of a test crash with a rigid 4-in. object, performed at 42 mph, was included in this testing. “Testing provided engineers with opportunities to modify design characteristics to better collision performance. The testing also was a valuable visual aid in design discussions” (Milton 2005, p. 2).

The Texas Transportation Institute designed and crash tested a 20-in. barrier in accordance with NCHRP report 350 recommendations (Ross et al. 1993). The Federal Highway Administration approved the use of this low profile barrier in 1996 “as a temporary barrier on the National Highway System (NHS) where there are few trucks, the highest impact speeds are expected to be in the 70 km/h [45 mph] range, and its use is requested by a State agency”(FHWA correspondence 1996).

Visibility and Sight Distance

As trees grow in close proximity to the traveled way, they may obstruct drivers’ line of sight. Vertical clearance, the ability to see through trees, and visibility at intersections and driveways must all be considered.

WSDOT’s sight distance criteria pertain to visibility at decision points. Sections 650, 910, and 920 of the *Design Manual* indicate that sight distances required depend on horizontal and vertical curvature, length of the curve, context (i.e., urban, rural, suburban), and the maneuver to be performed (e.g., stop, direction change, avoidance of an unexpected object in the roadway). The criteria focus on the need for adequate visibility in order for the drivers to perceive, react, and perform the required driving task. The Design Manual does not specify any regulations for the placement of street trees.

The *Roadside Design Guide* states that a vertical clear vision space from 3.3 feet to 10 feet above grade along all streets and at all intersections is desired (2002, p. 10-8).

In Florida, the clear sight zone controls both the placement of plants near intersections or pedestrian crossings and the diameter of the plantings in these locations (Lott and Graham 1995). A clear sight window must be maintained from 2 feet to 8.5 feet above the pavement surface. Special consideration must be given to the clear sight window at horizontal and vertical curve locations. The horizontal sight distances

approaching intersections on divided highways with speeds of between 35 to 45 mph ranges from 470 to 710 feet.

Street trees may diminish the visibility of pedestrians, particularly in low light. Figure 2-1 illustrates some of the potential pedestrian visibility limitations within a landscaped streetscape.



Figure 2-1. SeaTac – Pedestrians within Narrow Landscaped Median

The *Roadside Design Guide* states that a vertical clear vision space of from 3 feet to 10 feet above grade along all streets and at all intersections is desired. It also notes that visibility restrictions caused by landscaping must be considered. A key consideration is full visibility for both drivers and pedestrians at driveways (2002, p. 10-8).

IMPLEMENTATION CONSIDERATIONS

As noted above, there are some design standards that, if followed strictly, would preclude planting trees within certain types of medians or along sidewalks. However, in accordance with the statewide and national emphasis on Context-Sensitive Designs, innovative treatments are being implemented. The design of landscaped medians is a balance between maintaining safety and improving the aesthetics of the facility. Despite general guidelines in the AASHTO guides, there are no specific rules for what and how to plant in medians. In reality, the decisions are often a collaborative effort between the landscape architect and the design engineer, given their respective experience and

judgments about the location and type of trees and other vegetation in relation to their surrounding environment. Below are lessons learned from selected metropolitan areas. Table 2-1 summarizes the discussion below, including selected operating practices related to aesthetic median improvement on urban arterials.

Median Width and Length

In general, wide medians are considered more desirable than narrow medians because they reduce the likelihood of head-on collisions (Hadi et al. 1995). The Green Book suggests that any additional median width provides an added increment of safety and improved operation between intersections. Also, for maintenance crew safety, landscaping in very small islands should be avoided.

For the most part, the median width used by different jurisdictions varies from site to site. For example, in University Place, Washington, the median width is typically 8 to 12 feet (Public Works Standards 1999). In San Jose, California, the median width is typically 14 feet (Schultz e-mail 2002). San Jose generally does not plant on the narrow island tips along left-turn pockets, since plants placed in these locations are likely to get damaged by vehicles and can limit visibility. Similar rules have been adopted in Carrollton, Texas, where the median width ranges from 9 to 17 feet (Grier e-mail 2002). The North Carolina DOT states that for large trees, the median width has to be at least 30 feet in areas with posted speeds of less than 35 mph, and a minimum of 44 feet with posted speeds of between 35 to 45 mph (NC DOT, No Date). In Florida, the minimum width on 45 mph facilities is 19.5 feet, while it is 15.5 feet on facilities with speeds of 40 mph or less. The width next to left turn lanes is 3 feet at mid-block locations and commonly 4 feet at intersections. However, as little as 18 in. has been used when right-of-way is restricted (Florida DOT 1997).

The medians usually vary in length depending on how they fit between left turn pockets, although consideration for the flow of traffic will affect decisions on where left turn pockets should be provided.

Table 2-1. Summary of Selected Current State of Practice Guidelines Relating to Median and Roadside Landscaping Guidelines

Clear Zone	Median Width	Distance from Nose Cone	Vertical Clearance	Tree Spacing	Notes
AASHTO Green Book, 2001					
3.3 ft. clearance to roadside objects 1.5 ft. from curb face	Not defined	Not defined	Not defined	Not defined	1.5 ft. between curb face and object is an operational offset, not a clear zone
AASHTO Roadside Design Guide, 2002					
Min of 7 ft. to 10 ft. from the edge of traveled way for large tree	Not defined	Not defined	Desire a clear vision space from 3 ft. to 10 ft. above grade	Not defined	Landscaping very small islands should be avoided. Large trees should not be used at decision points such as island noses.
WSDOT Design Manual - Section 700					
35 mph or less – 10 ft. from edge of traveled way Varies with roadside slope and traffic volume: typical 40mph, 15 ft.; 45mph, 17 ft.	Not defined	Not defined	Not defined	Not defined	When evaluating new plantings or existing trees, consider the max allowable diameter of 4” measured at 6” above the ground when the tree has matured.
Florida Department of Transportation					
12 ft.- Urban roadside Treed medians \geq 15 ft. Min offset to a tree is 6 ft.	3 ft. next to left-turn lanes 19.5 ft. for 45mph, 15.5 ft. \leq 40mph	Not defined 4 ft. wide nose cone	Between 2 ft. to 8.5 ft. above the pavement surface as a clear sight window	So as not to impact sight distances	The intersection sight distances on 35-45 mph divided highways range from 470-710 ft. Curbed medians allowed on roads with speeds <50mph

Table 2-1. (continued)

Clear Zone	Median Width	Distance from Nose Cone	Vertical Clearance	Tree Spacing	Notes
North Carolina DOT					
<35 mph – 5 ft. from small tree, 10 ft. from large tree 35-45 mph – 8 ft. from small tree, 15 ft. from large tree	<35 mph – min of 30 ft. for large trees 35-45 mph – min of 44 ft. for large trees	60 ft. from nose cone	Min of 16 ft. above the entire pavement width Clear sight between 2 ft. and 6 ft. above roadway elevations	Sufficiently far apart	
Texas DOT					
30 ft. from the edge of the travel lane for plants of 4" caliper 15 ft. from the edge of the travel lane for plants less than 4" caliper	Min of 60 ft. for 4" mature caliper or greater Min of 30 ft. for less than 4" caliper	Vary with site conditions	Depends on species and site conditions	Depends on species and site conditions	Prefer not to place hard numbers on such issues. Designs are by collaboration between the landscape architects and the design engineers.
Arlington, Texas					
Min of 5 ft. from trunk of tree to curb	Typically 18 ft.	75 ft. from the nose cone where speed limits \geq 40 mph	Min of 10 ft. for all trees	Not defined	
Carrollton, Texas					
Not defined	9 ft. to 17 ft.	10 ft. from nose cone	Arborist uses common sense so that plants used do not impair visibility.	Not defined	Trees are not located in critical areas such as along the turn lane where visibility could be impaired.

Table 2-1. (continued)

Clear Zone	Median Width	Distance from Nose Cone	Vertical Clearance	Tree Spacing	Notes
Lincoln, Texas					
Min of 6 ft. from trunk of tree to curb	Not defined	Not defined	2 ft. to 6 ft.	Not defined	Leave sufficient space between individual trees and/or clumps of trees as “windows” for motorists to monitor the locations of vehicles in other traffic lanes.
Bellevue, Washington					
Not defined	4 ft.	Not defined	7.5 ft. vertical - branches can’t grow out into street over the curb	Not defined	
University Place, Washington					
Not defined	8 ft. to 12 ft.	Not defined		Not defined	
Redmond, Washington					
Not defined	Typically 12 ft.	Varies. No less than 15 ft.	Trim trees back as needed to ensure good sightlines and adequate clearance for vehicles	30 ft.	Follows WSDOT’s <i>Design Manual</i> . Use chanticleer pear tree so the fullest width is within 4 ft..
San Jose, California					
Not defined	Typically 14 ft.	Not defined	30” for shrubs 11 ft. for all trees	Not defined	Typically plantings in narrow islands along left turn pockets are likely to get damaged and can limit visibility.

Distance to Nose Cone

The nose cone is the end section of a median. The goals of this type of design guidance are to provide adequate site distance and avoid unnecessarily reduced visibility for drivers as well as pedestrians. Within the Texas DOT, no specific rule is available. In Arlington, Texas, 75 feet are required between the nose cone of a landscaped median and the first tree/shrub for speed limits of 40 mph or greater (http://www.ci.arlington.tx.us/park/forestry/forestry_masterplan_standards.html, accessed on 1/15/02 by Jennifer Nee). In Carrollton, Texas, it is typically 10 feet from the nose cone to the first shrub. Also, for the safety of maintenance crew, landscaping very small islands should be avoided. Florida's *Median Handbook* recommends a 4-foot median "nose cone" at intersections. It also makes an interesting point about the visibility of narrow medians at intersections, stating:

Carefully selected landscaping is the only effective way to provide excellent visibility of the median and median openings. A minimum traffic separator width of 1.8m (6') and preferable 2.5m (8.5') is needed for the median nose to be of sufficient width back-to-back of curbs to provide adequate area for vegetation to make it highly visible... Obviously the choice of vegetation and the landscaping design must ensure that sight distance is not obstructed. (Florida DOT 1997, p. 4-5)

Vertical Clearance

As noted above, the *Roadside Design Guide* states that a clear vision space of from 3 to 10 feet above grade along all streets and at all intersections is desired. But again, practice for vertical clearance varies from agency to agency. Whereas in San Jose the typical vertical clearance is 30 in. for shrubs and 11 feet for all trees, the Texas DOT's design recommendations depend on tree species and site conditions. In Carrollton, Texas, the arborist uses common sense so that visibility will not be impaired.

As noted above, Florida mandates that a clear sight window be maintained from 2 to 8.5 feet above the pavement surface (Lott and Graham 1995). Special consideration must be given to the clear sight window at horizontal and vertical curve locations.

Tree Spacing

No specific guidelines are available from the AASHTO guides. Generally, these

decisions depend on tree species and site conditions. Trees should be sufficiently far apart so that they do not limit visibility.

Tree Species Selection

While the type of trees selected for median landscaping is a matter of taste and varies depending on the geographic region of the country, the form and height of the species must be suitable for the width of the street. Trees must be carefully selected for size, height, and shape so that they will not obstruct the sight of pedestrians or drivers. The type of tree dictates the tree height and size, and tree configuration (cluster or linear) determines tree spacing.

As indicated in the NC DOT's *Guidelines for Planting within Highway Right-of-Way* (no date), safety is not the only criterion that governs the selection of plants. The NC DOT's recommendations are that "only low-growing shrubs are to be used in medians and close to the edge of shoulders to avoid need for continued severe pruning...Selection of appropriate plant material which will survive in the roadside environment is an important element in undertaking a highway planting project." Florida recommends selecting plants based on malleability, the tree's root system, and the quality of the tree or palm (Lot and Graham 1995, p. 4-32). Malleability refers to the ability of the plant to easily recover after it has been damaged. The handbook also notes that plants with multiple trunks are often more malleable than single-trunk plants, and they have the added benefit of being easier to maintain at or below the 4-in. maximum diameter.

In selecting the trees, a number of important factors should be considered (Food and Agriculture Organization 1989):

Space and line-of-sight limitations – Consider the type of trees and other vegetation in relation to their surrounding environment.

Tree configuration (cluster or linear) – Tree configuration should not obstruct the sight of drivers or pedestrians.

Environmental compatibility – Consider the suitability of the species to the climate, drainage, and soil. While planting one species can provide pleasing uniformity, planting several species of trees increases diversity and lessens the chance of catastrophic loss of all trees of one species from insects or disease.

Minimal maintenance – Trees with low maintenance requirements should be

selected; preferred species require little pruning or removal of fallen leaves.

Longevity – Trees should not be subject to wind-throw or breakage of large limbs, and should be able to survive in harsh soils and confined growing space.

Easy to establish – Trees should grow relatively quickly to the stage that they provide some amenity value.

ACCESS CONTROL

A report by Phillips, Carter, Hummer, and Foyle for the North Carolina Department of Transportation (2004) discussed the vehicular safety and operational impacts of access control, focusing particularly on competing treatments for mid-block left turns and the impacts these treatments have on the adjacent signalized intersections. The two competing treatments studied on four-lane highways were the two-way left turn lane (TWLTL) configuration and raised medians.

The cross-sectional safety study was conducted on 143 mid-block segments, and the predictive models were calibrated by using geometric, land-use, collision, and volume data. The prediction models used in this study were of the negative binomial form.

Phillip et al. reported that the significant factors in predicting the frequency of mid-block accidents include segment length, traffic volume, cross-section type (raised median or TWLTL), predominant land use, and approach density². Raised medians were associated with fewer accidents than the TWLTL cross-section in residential and industrial areas. Also, they were associated with fewer accidents in business and office areas when the approach densities were low. For higher approach densities, TWLTLs were slightly safer at low traffic volumes, while raised medians were slightly safer at high volumes.

Phillips et al. (2004) used designated volumes of less than 35,000 vehicles per day as low volumes and more than 35,000 vehicles per day as high volume. Thus the SeaTac study would fall into the high-volume category. They also designated different levels of approach density, ranging from between 0 and 25 approaches per mile (low density) and 25 to 90 approaches per mile (high density).

The second portion of the report by Phillips et al. focuses on the safety and

² Approach Density: the number of driveways per mile inclusive of both sides of the roadway.

operational impacts of U-turn movements at signalized intersections adjacent to raised medians. They investigated U-turn movements from exclusive left turn lanes at 78 intersections, a third of which were selected because they were identified as U-turn “problem sites.” In spite of this bias, the authors found that 65 of the 78 intersections did not have any U-turn accidents in the three-year study period. The U-turn collisions at the remaining sites ranged from between 0.33 and 3 per year. Some of the factors that were correlated with a significant difference between sites with and without U-turn collisions included the presence of a second left turn lane, presence of right turn overlap, differences in the number of morning and afternoon left turn movements, and differences in the number of conflicting morning and afternoon right turn movements. The operational impacts of these movements (measured by differences in average vehicular headway) showed a 1.5 to 1.8 percent decrease in saturation flow for every 10 percent increase in U-turn percentage.

Phillips et al. concluded that, in general, raised medians are safer at mid-block locations than TWLTLs, and they have minimal safety or operational impacts at adjacent intersections.

ROADWAY GEOMETRY

Milton and Mannering (1998) investigated the effects of highway geometrics and traffic-related elements on the frequency of vehicle accidents. The models developed split the Washington State data into two sections – Eastern and Western Washington – in order to capture the significant weather and terrain differences in these geographic areas. Their results indicated that some geometric variables, including vertical grade, narrow right and left shoulders, number of lanes, sharp horizontal curve radius, tangent length, and narrow lane widths, were significant determinants of accident frequency. Additional significant traffic variables included in their models were posted speed, traffic volume, and truck and peak hour percentages.

Elasticities computed for each of the variables indicated significant differences between the Western and Eastern Washington models and the variables that most strongly affect accident frequencies. The strongest indicators in Western Washington were the number of lanes and posted speed, whereas in Eastern Washington they were narrow lanes and narrow right shoulders.

This research highlighted the importance of including geometric characteristics in predictive accident frequency models.

RESEARCH APPROACH

The review of literature presented above indicated the types of variables that would most likely be significant in this research. The review also highlighted some of the topics of particular interest, namely the effects of landscaped medians on the overall safety of the urban highway. This investigation considered traffic characteristics (volumes; speed limits were constant before and after, and speed studies were not available); geometric variables such as number and width of lanes, median widths, and curvature and alignment; characteristics specific to each accident (type, environmental conditions, driver condition, etc); the level of access; and specific variables relating to the presence and placement of trees. The method of collecting these data, and the specific variables collected, are discussed further in Chapter 3.

Statewide Accident Types and Severities

The WSDOT maintains accident records for all state highways, and compiles the Washington State Highway Accident Report. The most recent of these reports was released in 1996 (WSDOT 1996). This report contains statewide collision rates, as well as collision and fatal accident rates for each county, WSDOT region, and differing types of facilities (e.g., principle urban arterials). It also reports the percentages of the most frequent types of accidents, the types of objects struck most often in non-fatal and fatal accidents, the level of injury sustained, and the leading contributing circumstances.

Accident Frequency Models: Poisson/Negative Binomial

Count data such as the frequency of accidents have been modeled with the Poisson or negative binomial (NB) models (Milton and Mannering 1998; Sullivan 2004; Philips et al. 2004). These models are appropriate for modeling accident frequencies along a highway with varying characteristics (e.g., changes in traffic volumes, geometric conditions, levels or types of access) because they predict non-negative integer values that are drawn from a distribution approximating the occurrence of rare events (Washington et al. 2003, p. 241). The Poisson model is used when the variance within the

data is approximately equal to the mean (i.e., $E[n_i] = \text{Var}[n_i]$). In accident frequency data this condition is often violated, typically with the variance being greater than the mean. In this case, the NB model may be more appropriate.

Sullivan developed accident prediction models based on the Poisson and negative binomial structures (2004) for the Phase III report on urban highways with treed and tree-less medians. The models were compared, and the NB model was selected as appropriate to model the data. This conclusion is in accord with current trends in accident data analysis.

Ulfarsson and Shankar (2003) investigated the use of the negative multinomial (NM) model for cross-sectional panel (i.e., multiple years) data with serial correlation to model the frequency of median crossover accidents on Washington State highways. They compared this model with negative binomial (NB) and random-effects negative binomial (RENB) models developed with the same data set by Shankar et al. (1998). They found that the NM model significantly outperformed both the NB and RENB models in terms of fit, with a statistically higher likelihood at convergence.

Two types of serial correlation are associated with panel data, as discussed by Ulfarsson and Shankar (2003, p. 196): serial correlation among observations at the same location across years, and among observations from the same time period. In addition to these serial correlation issues with panel data, this data set may exhibit serial correlation among observations from locations geographically close to each other. Given the complexity of the NM model, and the anticipated serial correlation, Poisson/NB models were developed for this project instead, inline with the majority of current accident frequency analyses.

Accident Severity Model: Multinomial Logit

Discrete outcome modeling investigates an inherently different type of phenomenon than frequency modeling. The discrete outcomes of a physical event, such as a vehicular accident, depend on numerous inputs, which may vary in significance from one type of outcome to another. For example, an accident can be classified as resulting in a severity level of property damage only (PDO), some type of injury, or a possible injury. Each of these categories of severity may be influenced by different factors. The highest level of severity may result from accidents involving higher traveling speeds and vehicles

traveling in opposite directions (such as head-on collisions). On the other hand, PDO accidents often involve slower speeds and rear end collisions. In order to improve the safety of a highway most efficiently, it is desirable to reduce the most severe injury accidents. It is also helpful to understand the relative probabilities of the various levels of accident severity, in order to quantitatively compare the safety of the highway before and after a roadway construction project.

The multinomial logit (MNL) model has been used to determine contributing factors for each member of a complete set of possible outcomes, e.g., the factors that contribute most significantly to the most severe injury in an accident for each level of injury severity, as noted above (Lee and Mannering 1999; Shankar et al. 2000; Khorashadi et al. 2005). The results then indicate the overall probability of each accident injury severity level for the analysis timeframe and geographic parameters. In this way, we were able to approximate the probability of each injury severity level for the redevelopment projects and compare them before and after the construction had been completed. This allowed us to quantify the changes in safety as measured by injury severity.

One concern with multinomial logit models is the presence of shared unobserved characteristics between some severity levels. The model assumes that the error terms of the discrete outcomes are independent and identically distributed. Therefore, there is a limitation assuming the independence of irrelevant alternatives (IIA). In the case that there are unobserved characteristics shared between some of the severity levels, the IIA assumption is violated. This will result in probabilities that are incorrect (Washington et al. 2003, p. 274). Several tests can be performed to determine whether significant, unobserved variables are shared between severity levels. One of these is the Small-Hsiao (1985) IIA test, which produces a chi-square statistic that can be compared to the chi-square distribution. If it is significant, then there is evidence of shared unobserved variables, and remedial action must be taken.

CONCLUDING REMARKS

Existing AASHTO design guides focus on roadway improvements and removal of hazardous trees, and no detailed guidelines are provided with regard to new planting, although some guidance is available from design information used by state DOTs and

city roadway agencies. Furthermore, little published information is available on the actual or expected effect of landscaped medians on accident rates in urban areas. Recognizing that landscaped medians are just one of the elements that affect motorists' driving experience, it may be difficult to differentiate the effects of trees in medians from the effects of other geometric design features on roadway safety.

While visibility restrictions with landscaped medians appears to be universally recognized as deserving careful consideration, the available design guidance provides considerable latitude in making decisions about tree location, spacing, type, and the necessity of using barriers to separate trees and traffic. In the absence of specific recommendations and/or standards, it may be necessary and desirable to conduct individual analyses and to work collaboratively with engineer designers, landscape designers, and arborists to determine the appropriate design and treatment.

Little scientific research has examined the tradeoffs between aesthetics and safety within the urban context.

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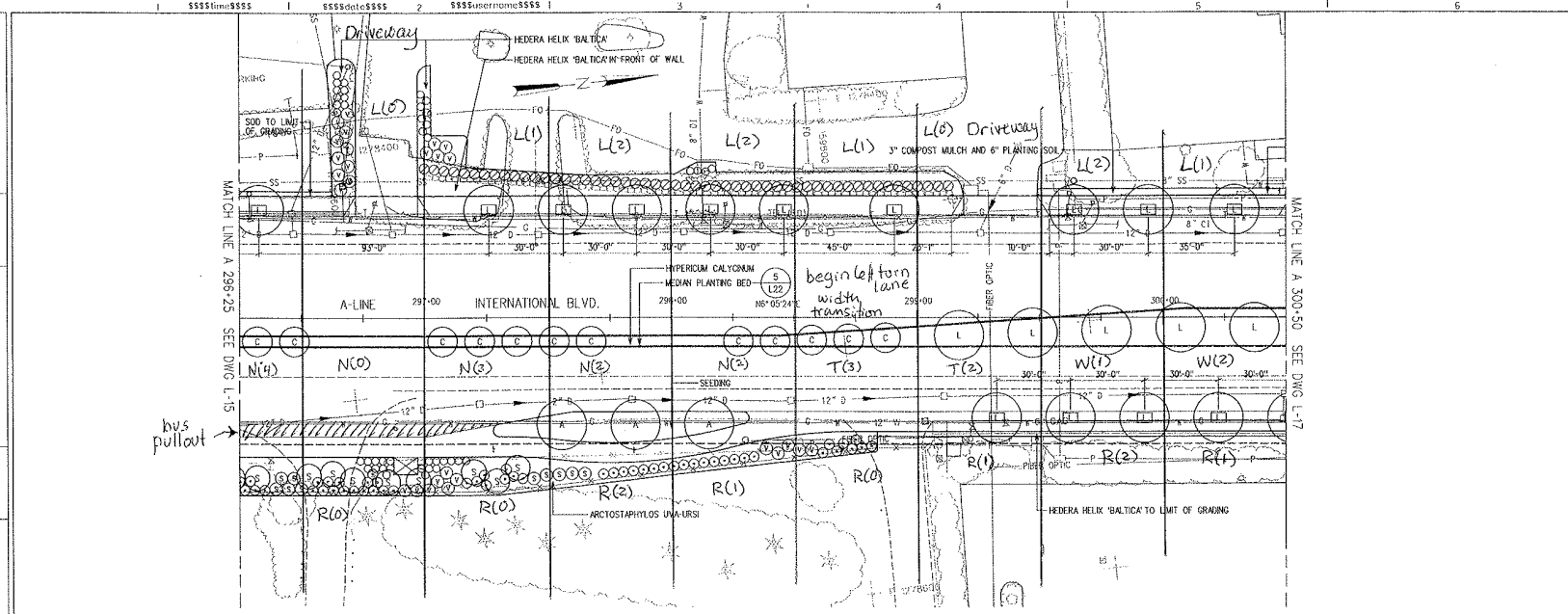
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APPENDIX B

MEDIAN AND ROADSIDE PLANTING PLANS AND DATA COLLECTION PROCESS, SEATAC

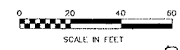


PLANT SCHEDULE

QTY	SYMBOL	BOTANICAL NAME COMMON NAME	NOTES	QTY	SYMBOL	BOTANICAL NAME COMMON NAME	NOTES
3	A	ACER RUBRUM 'RED SUNSET' / RED MAPLE	2 1/2" CAL. SYMMETRICAL BRANCHING PATTERN, B&B	NC	(1) (2)	OSMAREA BURKWOODII / NON	5 GALLON, 5'-0" O.C.
19	L	LIQUIDAMBAR STYRACIFLUA / AMERICAN SWEET GUM	2 1/2" CAL. SYMMETRICAL BRANCHING PATTERN, B&B	42	(3) (3)	SPIREA BULMADA 'ANTHONY WATERER' / ANTHONY WATERER SPIREA	3 GALLON, 3'-0" O.C.
9	S	AMELANCHIER 'AUTUMN BRILLIANCE' / SERVICEBERRY	7'-8" HEIGHT, B&B, MULTI-STEM (3-5)	27	(4) (4)	VIBURNUM PFLIC. TOMENTOSUM 'WAKES' / DOUBLEFILE VIBURNUM	5 GALLON
NC	D	CORNUS KOUSA / KOUSA DOGWOOD	7'-9" HEIGHT, B&B, MULTI-STEM (3-5)	53	(5) (5)	VIBURNUM TIMOS 'SPRING BOUQUET' / NON	24" HEIGHT, B&B
NC	P	PRUNUS NEGRA / AUSTRIAN BLACK PINE	8" HEIGHT, B&B	1,537	SEE PLAN	ARCTOSTAPHYLOS UVA-URSI / KORDBRANK	1 GALLON, 2'-0" O.C.
12	C	PYRUS CALLERYANA 'CHANTICLEER' / CALLERY PEAR	2" CALIPER, B&B	1,803	SEE PLAN	HEDERA HELIX 'BALTICA' / ENGLISH Ivy	1 GALLON, 1'-6" O.C.
10	(3) (3) (3)	ABUTILUS UNEDO 'COMPACTA' / DWARF STRAWBERRY TREE	5 GALLON, 5'-0" O.C.	1,565	SEE PLAN	HYPERICUM CALYCHOM / ST. JOHN'S WORT	1 GALLON, 1'-6" O.C.
52	(4) (4) (4)	EVONYMUS ALATUS 'COMPACTA' / BURNING BUSH	24" HEIGHT, B&B				

PLANTING NOTES

1. ALL GROUND COVER / SHRUB BEDS SHALL RECEIVE 6" OF PLANTING SOIL AND 3" OF COMPOST MULCH.
2. ALL AREAS TO BE SEEDS SHALL RECEIVE 4" OF PLANTING SOIL.
3. SEE DRWG L-22 FOR DETAILS OF PLANTING SOIL IN MEDIAN.



NAKANO
DENNIS
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DESIGN	EM, DD	B
DRAW	EM	D
CHECK	DD	S
APPROVED	DD	

Other Characteristics to note
bus stop/pullout # of lanes
driveway intersection
sidewalk signpost
turn lanes

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NOT TO SCALE
THIS IS ONE VIEW OF THE PROJECT. SEE OTHER VIEWS FOR COMPLETE INFORMATION. IF NOT ONE VIEW OF THE PROJECT, SEE OTHER VIEWS FOR COMPLETE INFORMATION.

CITY OF SEATTLE
PUBLIC WORKS DEPARTMENT
INTERNATIONAL BOULEVARD
PHASE II WIDENING AND
SIGNAL MODIFICATION
SR 99 MP 17.52 TO MP 18.35

INTERNATIONAL BOULEVARD TSPM PHASE II
SR 99 MP 17.42 TO MP 18.31
PLANTING PLAN

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DATE DEC 1995
PROJ 153006.A1

Note the vertical lines marked on the plan sheets. These lines denote 50-foot increments along the centerline of the project. The roadway and roadside characteristics of each 50' section were tabulated in a spreadsheet similar to the one above. The width of the median, number of trees within the median and along each sidewalk, the presence of driveways, bus stops, intersections, and turn lanes were all recorded. When all of these characteristics were verified using a visual check on SR View or other recorded video of the highway, the data were then transposed to adjust for the difference between 50' increments and 1/100 of a mile.

The signalized intersection with South 195th Street shown on page 1 of this appendix is highlighted in the table above.

APPENDIX C

FINAL MODEL VARIABLE DESCRIPTIVE STATS AND CORRELATION MATRICES

FREQUENCY DESCRIPTIVE STATISTICS

Before Conditions

Table 1 – SeaTac Before – Descriptive Statistics with Intersections

Variable	Minimum	Maximum	Mean	Std.Dev.	
Avg ADT	31229	43281	36962	4313.2	
VGB	0.0	4.3	0.6602	1.1428	
HCrvAng	0.0	1.0	0.2245	0.4183	
INT	0.0	1.0	0.0561	0.2307	
WideWShld	0.0	1.0	0.8827	0.3227	
WideEShld	0.0	1.0	0.8673	0.3401	
TurnE	0.0	1.0	0.3265	0.4701	
Curb	0.0	1.0	0.3061	0.4621	
EastAC	0.0	1.0	0.1582	0.3658	

Table 2 – SeaTac Before – Descriptive Statistics without Intersections

Variable	Minimum	Maximum	Mean	Std.Dev.	
AvgADT	31229	43281	36902	4331.8	
VGB	0.0	4.3	0.6863	1.1623	
WestShld	0.0	12.0	7.6541	2.0771	
EastAC	0.0	1.0	0.1676	0.3745	
Curb	0.0	1.0	0.3243	0.4694	
TurnE	0.0	1.0	0.3459	0.4770	
Bus	0.0	1.0	0.2324	0.4235	

After Conditions

Table 3 – SeaTac After – Descriptive Statistics with Intersections

Variable	Minimum	Maximum	Mean	Std.Dev.	
AvgADT	31615	44594	37184	4416.2	
VGB	0.0	4.3	0.6602	1.1428	
INT	0.0	1.0	0.1327	0.3401	
LaneSep	0.0	1.0	0.8878	0.3165	
WestAC	0.0	1.0	0.4337	0.4969	
TurnE	0.0	1.0	0.5969	0.4918	
TTrees	0.0	8.0	3.2449	1.9378	

Table 4 – SeaTac After – Descriptive Statistics without Intersections

Variable	Minimum	Maximum	Mean	Std.Dev.	
AvgADT	31615	44594	36971	4423.5	
VGB	0.0	4.3	0.7021	1.1910	
WestAC	0.0	1.0	0.5000	0.5015	
LandScp	0.0	1.0	0.7059	0.4570	
Curb	0.0	1.0	0.1824	0.3873	
TurnE	0.0	1.0	0.6118	0.4888	
BothDrv	0.0	1.0	0.1000	0.3009	
ETrees	0.0	4.0	1.2588	0.7868	

FREQUENCY CORRELATION MATRICES

Before Conditions

Table 5 – SeaTac Before – Correlation Matrix with Intersections

	ADT	VGB	HCrv Ang	INT	Wide WShld	Wide EShld	TurnE	Curb	East AC
ADT	1.000	0.161	-0.243	0.057	-0.140	-0.088	-0.040	0.081	0.147
VGB	0.161	1.000	-0.176	-0.094	-0.008	0.026	-0.135	-0.142	-0.043
HCvAng	-0.243	-0.176	1.000	0.081	0.082	0.102	-0.166	0.120	-0.200
INT	0.057	-0.094	0.081	1.000	-0.393	-0.493	-0.170	-0.162	-0.106
WWShld	-0.140	-0.008	0.082	-0.393	1.000	0.278	-0.017	-0.171	-0.190
WEShld	-0.088	0.026	0.102	-0.493	0.278	1.000	-0.081	-0.034	-0.078
TurnE	-0.040	-0.135	-0.166	-0.170	-0.017	-0.081	1.000	0.482	0.026
Curb	0.081	-0.142	0.120	-0.162	-0.171	-0.034	0.482	1.000	0.046
EastAC	0.147	-0.043	-0.200	-0.106	-0.190	-0.078	0.026	0.046	1.000

Table 6 – SeaTac Before – Correlation Matrix without Intersections

	ADT	VGB	WestShld	EastAC	Curb	TurnE	Bus
ADT	1.000	0.184	-0.095	0.158	0.094	-0.032	-0.037
VGB	0.184	1.000	-0.118	-0.053	-0.161	-0.155	-0.042
WShld	-0.095	-0.118	1.000	-0.212	-0.196	-0.054	-0.019
EastAC	0.158	-0.053	-0.212	1.000	0.029	0.008	0.096
Curb	0.094	-0.161	-0.196	0.029	1.000	0.467	0.330
TurnE	-0.032	-0.155	-0.054	0.008	0.467	1.000	0.380
Bus	-0.037	-0.042	-0.019	0.096	0.330	0.380	1.000

After Conditions

Table 7 – SeaTac After – Correlation Matrix with Intersections

	ADT	VGB	INT	LaneSep	WestAC	TurnE	TTrees
ADT	1.000	0.114	0.124	-0.033	0.238	-0.108	0.072
VGB	0.114	1.000	-0.094	0.019	0.178	0.027	0.020
INT	0.124	-0.094	1.000	-0.671	-0.342	-0.077	-0.446
LaneSep	-0.033	0.019	-0.671	1.000	0.246	0.037	0.497
WestAC	0.238	0.178	-0.342	0.246	1.000	-0.016	0.416
TurnE	-0.108	0.027	-0.077	0.037	-0.016	1.000	-0.084
TTrees	0.072	0.020	-0.446	0.497	0.416	-0.084	1.000

Table 8 – SeaTac After – Correlation Matrix without Intersections

	ADT	VGB	WestAC	LandScpM	Curb	TurnE	BothDrv	ETrees
ADT	1.000	0.176	0.319	0.133	-0.056	-0.084	-0.057	0.056
VGB	0.176	1.000	0.160	-0.014	-0.052	0.016	0.053	-0.090
WestAC	0.319	0.160	1.000	0.129	-0.107	-0.048	-0.333	0.015
LandScpM	0.133	-0.014	0.129	1.000	-0.732	-0.223	-0.043	-0.001
Curb	-0.056	-0.052	-0.107	-0.732	1.000	0.189	0.096	0.077
TurnE	-0.084	0.016	-0.048	-0.223	0.189	1.000	-0.217	0.001
BothDrv	-0.057	0.053	-0.333	-0.043	0.096	-0.217	1.000	-0.235
ETrees	0.056	-0.090	0.015	-0.001	0.077	0.001	-0.235	1.000

SEVERITY DESCRIPTIVE STATISTICS

Before Conditions

Table 9 – SeaTac Before – Severity Model Descriptive Statistics

Variable	Minimum	Maximum	Mean	Std.Dev.	
Rend	0	1	0.4140	0.4927	
lcar	0	1	0.0869	0.2817	
Night	0	1	0.3142	0.4644	
Sswipe	0	1	0.1109	0.3141	
OppDir	0	1	0.0869	0.2817	
Mcars	0	1	0.1479	0.3551	
BkPd	0	1	0.0462	0.2100	
DUI65	0	1	0.0388	0.1932	
Fobj	0	1	0.0591	0.2360	
Eject	0	1	0.0092	0.0957	
LnSep	0	1	0.3475	0.4763	
DrkWet	0	1	0.1553	0.3623	

After Conditions

Table 10 – SeaTac After – Severity Model Descriptive Statistics

Variable	Minimum	Maximum	Mean	Std.Dev.	
lcar	0	1	0.0691	0.2538	
wtrees	0	2	0.1312	0.4301	
DUInight	0	1	0.0355	0.1850	
Sswipe	0	1	0.0957	0.2943	
OppDir	0	1	0.3351	0.4722	
Mcars	0	1	0.1046	0.3061	
BkPd	0	1	0.0301	0.1710	
DUI65	0	1	0.0479	0.2136	
Fobj	0	1	0.0532	0.2245	
LnSep	0	1	0.2004	0.4004	
RendInt	0	1	0.2695	0.4438	

SEVERITY CORRELATION MATRICES

Before Conditions

Table 11 – SeaTac Before – Severity Model Correlation Matrix

	Rend	lcar	night	Swipe	OpDir	Mcars	BkPd	DUI65	Fobj	Eject	LnSep	Dkwet
Rend	1.000	-.259	-.044	-.297	-.259	0.284	-.185	-.014	-.195	-.081	-.015	-.029
lcar	-.259	1.000	0.159	-.109	-.095	-.128	0.651	0.006	0.507	0.107	-.046	0.085
night	-.044	0.159	1.000	-.049	0.088	-.046	0.098	0.214	0.134	0.018	-.093	0.391
Sswipe	-.297	-.109	-.049	1.000	-.109	-.097	-.078	-.041	-.089	-.034	-.011	-.103
OppDir	-.259	-.095	0.088	-.109	1.000	0.019	-.037	0.074	0.062	0.039	0.147	0.085
Mcars	0.284	-.128	-.046	-.097	0.019	1.000	-.092	-.057	-.016	-.040	-.009	0.008
BkPd	-.185	0.651	0.098	-.078	-.037	-.092	1.000	-.044	-.055	-.021	0.006	0.076
DUI65	-.014	0.006	0.214	-.041	0.074	-.057	-.044	1.000	0.152	0.081	-.046	0.099
Fobj	-.195	0.507	0.134	-.089	0.062	-.016	-.055	0.152	1.000	-.024	0.031	0.109
Eject	-.081	0.107	0.018	-.034	0.039	-.040	-.021	0.081	-.024	1.000	0.011	0.012
LnSep	-.015	-.046	-.093	-.011	0.147	-.009	0.006	-.046	0.031	0.011	1.000	-.013
DrkWet	-.029	0.085	0.391	-.103	0.085	0.008	0.076	0.099	0.109	0.012	-.013	1.000

After Conditions

Table 12 – SeaTac After – Severity Model Correlation Matrix

	lcar	wtrees	DUInite	Swipe	OpDir	Mcars	BkPd	DUI65	Fobj	LnSep	RendInt
lcar	1.000	-0.002	0.061	-0.089	-0.193	-.093	0.606	0.037	0.621	0.091	-0.166
wtrees	-0.002	1.000	-0.036	0.209	-0.208	0.044	0.019	-0.049	0.038	0.589	-0.120
DUInite	0.061	-0.036	1.000	-0.062	0.026	-.034	0.022	0.810	0.168	0.096	-0.008
Sswipe	-0.089	0.209	-0.062	1.000	-0.231	-.013	-.057	-0.045	-.077	0.123	-0.198
OppDir	-0.193	-0.208	0.026	-0.231	1.000	-.120	-.103	-0.001	-.168	-0.308	-0.431
Mcars	-0.093	0.044	-0.034	-0.013	-0.120	1.000	-.060	-0.050	0.022	0.104	0.093
BkPd	0.606	0.019	0.022	-0.057	-0.103	-.060	1.000	0.009	-.042	-0.011	-0.107
DUI65	0.037	-0.049	0.810	-0.045	-0.001	-.050	0.009	1.000	0.095	0.054	0.032
Fobj	0.621	0.038	0.168	-0.077	-0.168	0.022	-.042	0.095	1.000	0.158	-0.144
LnSep	0.091	0.589	0.096	0.123	-0.308	0.104	-.011	0.054	0.158	1.000	-0.094
RendInt	-0.166	-0.120	-0.008	-0.198	-0.431	0.093	-.107	0.032	-.144	-0.094	1.000