# The Safety Effects of Urban Principle Arterial Streetscape Redevelopment Projects Including Street Trees: A Context-Sensitive Case Study

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# The Safety Effects of Urban Principle Arterial Streetscape Redevelopment Projects Including Street Trees: A Context-Sensitive Case Study

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**ABSTRACT**

This report documents safety performance of landscaped medians and other streetscape improvements on State Route (SR) 99 in Washington State. Findings contained in this report are based on a before-and-after study of streetscape improvements made in SeaTac, Washington.

Findings from the first two phases of SeaTac's redevelopment project analyses are shown and indicate no significant change in frequency or severity of crashes. Crashes in the combined study area decreased slightly, while SeaTac Phase 2 showed a slight increase. A shift in crash locations occurred, with fewer mid-block and increased intersection crashes. U-turn crashes increased after construction, from four to 35 within three years. These changes relate directly to the access control effects of the medians

The number of crashes reporting striking a fixed-object decreased in the Phase 1 roadway segment but increased in the Phase 2 segment. When trees were involved, the small size of the trees appears to have limited the severity of the resulting crash, increasing the likelihood that they would be classified as "property damage only." Concern related to the future growth of trees and the corresponding increased severity is identified. The findings also shows that placing trees in narrow medians and near road segments with turning movements resulted in high levels of tree strikes.

## PROJECT INTRODUCTION

Legacy arterials such as State Route (SR) 99 in the greater Seattle area 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 is considered by many cities, which developed around the route, 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.

Due to concerns for the safety of the traveling public, and in an effort to increase the attractiveness of the local communities, cities along arterials like SR 99 have proposed and are implementing streetscape redevelopment plans. SeaTac was the first city to propose this type of streetscape redevelopment in Washington State. Of specific interest is whether the aesthetically pleasing landscaped designs change the accident rates and characteristics of these arterials.

## PROJECT BACKGROUND

The Washington State Department of Transportation (WSDOT) adopted an in-service evaluation process to evaluate a broad range of collision, environmental, operational, and maintenance situations in the urban context. This evaluation is intended to help WSDOT and its partner cities understand the overall impacts and benefits of these context sensitive designs. The evaluation will help inform new urban design policy by presenting to decision-makers quantitative and qualitative measures of design tradeoff impacts within the urban context.

Changes implemented by the cities included improvements in three general areas: roadway, roadside, and pedestrian facilities. Improvements to the roadway included converting two-way left turn lanes (TWLTL) into landscaped medians with left turn/U-turn pockets, widening the roadway, adding business access and transit (BAT) lanes, installing street lighting, and making signal improvements. Improvements to the roadside environment included consolidating and defining driveways/access points, undergrounding utilities, and improved stormwater facilities. Pedestrian-oriented improvements 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. 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 (raised medians, 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, some stakeholders view reduced speeds as a benefit to safety and livability, while 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. A 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 (*1*). These potential impacts include an increase in the likelihood of severe injuries involving tree collisions (*2*),(*3*), 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 effects that must be balanced to achieve a safe, efficient, and attractive facility that meets the needs of the varied stakeholders.

## METHODOLOGY

The data needs were initially defined to include crash experience, roadway geometries, traffic characteristics, level of access, and specific elements related to the median and roadside trees (*4), (5), (6*).

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

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. 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. The multi-variate models developed follow the Poisson and multinomial logit forms. Negative binomial models were also investigated, but the data were not found to be overdispersed (*7*). The results of these models are described below.

SeaTac 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.

## FINDINGS

SeaTac exhibited high crash rates in the before and after periods with no significant changes occurring between the two phases. The locations of crashes did shift significantly. In the before period, more crashes occurred at mid-block locations than in the after period (see discussion below and St. Martin et al.(*7*) for greater detail concerning changes in accident characteristics). After construction, U-turn crashes increased from four crashes to 35 within three years. This shift was expected, given the extent of turning movement restrictions and access controls imposed by the installed medians. However, the size of the increased crash rate at the intersections was a concern.

### Summary Crash Occurrence: Types, Locations, Severities, and Rates

*Phase 1 Summary*

The first phase of SeaTac's redevelopment project extends from south of the intersection with South 188$^{th}$ Street to just north of S. 170$^{th}$ Street, (State Route Mile Post (SRMP) 18.28-19.47). The data collected for this project were from 1993 to 1995 for the before conditions, and from 1999-2001 for the after conditions.

The number of crashes after construction decreased 14 percent, from 395 to 341 along the 1.20-mile long section within the three-year analysis timeframe. This results in crash rates of 8.10 crashes per million vehicle miles traveled (mvmt) before, and 6.86 per mvmt after. The locations of the crashes were more concentrated at intersections, although at most of the individual intersections the number decreased. The severity of fixed-object crashes was lower, and there was a general decrease in the severity of injuries in all crashes. The types of crashes that occurred most frequently changed, most notably an increase in left turn crashes and a decrease in rear-end crashes. Therefore, through 2001, the landscaped medians with trees less than 6 in. in diameter did not worsen crash occurrences within this project area and analysis timeframe, and by several measures the crash experience improved following the streetscape redevelopment project. The bicyclist and pedestrian crash occurrence has improved following project construction (from four to one bicyclist and from 10 to seven pedestrian crashes).

*Phase 2 Summary*

The second phase of the project extends from south of the intersection with S. 200th Street to just south of S. 188th Street (SRMP 17.52-18.28), where it meets up with the south end of Phase 1. The data collected for this project were from 1994 to 1996 for the before conditions, and from 1999-2001 for the after conditions.

The number of crashes *increased* by 53 percent, from 146 to 223 along the 0.77-mile long section within the three-year analysis timeframe. This results in crash rates of 3.63 crashes per mvmt before, and 5.64 per mvmt after. As with Phase 1, the characteristics and location of the crashes shifted. The number of rear end, driveway, and entering at angle crashes decreased, and sideswipes and left turn crashes increased. Similar to Phase 1, there were fewer of the most severe injury crashes. The number of fixed-object crashes increased, but they exhibited decreasing injury severity levels. After the project was completed, four accident reports noted at least one tree was struck resulting in only one crash with any evident injury. The overall crash rate increased following the construction of the Phase 2 project, and yet both the bicyclist and pedestrian crash experience improved slightly (from two to one bicyclist and from eight to seven pedestrian crashes).

*Tree Maintenance*

As noted above, SeaTac provided maintenance reports of trees replaced on the Phase 1 and 2 project areas. Within the 1999-2001 analysis time frame, 36 median trees were replaced, 90 percent reportedly due to being struck by vehicles. These incidents represent interactions between vehicles and median trees, even if they did not result in sufficient damage to the vehicle or occupant to warrant being reported to the police as a collision. However, just the fact that the incidents were not reported does not mean necessarily that they were not sufficiently damaging to warrant being reported as a collision. Crashes are under-reported as it is, and tree collisions are no exception.

Many of the accidents involving trees may not have resulted in significant injuries, or possibly even very much property damage given the trees are small. However, the rate of incidents could result in an increased injury experience as the trees grow larger and become more rigid.

*SeaTac Descriptive Analysis Summary*

The tree-strike and replacement experience following the completion of Phases 1 and 2 resulted in revisions to SeaTac's landscaping plans that precluded planting trees in narrow medians or within the influence area of intersections. Within this project context, it was determined that this placement resulted in frequent tree hits, necessitating repeated replacement of trees. These revisions were put into effect in the third and fourth phases of SeaTac's streetscape redevelopment. Other cities have paid head to their findings, precluding the placement of trees within narrow medians approaching intersections and along left-turn lanes.

Prior to the construction of these projects, a total of 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 collisions (19 in Phase 1 and 16 within Phase 2) within three years. The distribution of injuries included property damage only (PDO) (20), evident injury (7), and possible injury (8). The U-turn behavior change was highly probably, given the extent of the restrictions on turning movements across the highway. According to Philip et al. (*5*), the changes in safety at intersections following the construction of a project replacing a TWLTL with medians are minimal. The evidence here suggests there is a significant increase in the frequency of crashes (and specifically U-turn crashes) and in the 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 crash rates for the SeaTac Phase 1 and 2 projects exceed the statewide and regional crash rates. The 1996 statewide average crash rate for highway facilities classified as Urban Principle Arterials was 2.97 per mvmt. This section of SR 99 is within WSDOT's Northwest Region, and the average crash rate for all facilities in this region was 2.12 per mvmt. From this it can be concluded that the overall crash rates along these sections of SR 99 were higher than those on similarly classified statewide routes and within the WSDOT region for the analysis timeframe. This is true for both the before and after conditions, though Phase 1 shows a decrease in crash rate following the construction of the redevelopment project, while Phase 2 shows an increase. Following the completion of additional projects along SR 99, the trends in crash rates and severities will be clearer. Currently there is insufficient evidence to indicate that the crash rate increase in Phase 2 is directly related to the planting of trees within the median and along the sidewalks.

## Modeling Results

Statistical models have been developed to model the frequency and severity of crashes within both project areas before and after the construction of the streetscape redevelopment projects.

*Crash Frequency Models*

The crash frequencies are modeled with Poisson or negative binomial models (*7*). In all of the final models the dispersion parameter, $\alpha$, is not significant (t-stat <1.96), and we conclude that the data are not overdispersed and the Poisson regression model is appropriate.

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

The discussion in the sections above illustrate that intersections have high concentrations of crashes compared to mid-block locations. In order to address the possibility that the intersection variable might be the strongest predictor of crash frequencies, we will first develop models that include all crashes within the Phase 1 and Phase 2 project areas, and second that exclude the crashes at all intersections. This will allow us to investigate the effects of the streetscape redevelopment projects on the entire redeveloped route as well as the mid-block sections, which have undergone significant changes in geometry and in allowed traffic movements. In addition, Phases 1 and 2 will be analyzed together, because of the similarity in the features of the redevelopment projects and the overall length of these sections, which together measure approximately two miles. Issues of heteroskedaciticity arise with shorter sections given the variation of crash frequencies along the sections based on the intersection and mid-block differences.

Initially, four frequency models were developed, two for the Before conditions, and two for the After conditions.

**SeaTac Phases 1 and 2 Before Conditions** The model results described below in Table 1 represents the conditions existing prior to and following the construction of the Phase 1 and 2 streetscape redevelopment projects in SeaTac. Variables listed without a coefficient value were found to be statistically insignificant in the final model listed.

Table 2 lists the results for the final models that exclude the crashes that occurred at intersections.

**TABLE 1 SeaTac Before and After – Poisson Regression Models with Intersection Crashes**

| Independent Variable | | Coefficient (t-stat) | |
|---|---|---|---|
| | | Before | After |
| Constant | | -2.1833 (-4.3540) | 0.46561 (0.9500) |
| Average ADT | Average daily traffic volumes, averaged over the three year timeframe | 0.96556E-04 (8.0900) | 0.23117E-04 (1.8690) |
| Vertical Grade | Vertical grade back in % | -0.26888 (-4.3700) | -0.55678 (-6.8670) |
| Horizontal Curvature Angle | The outside horizontal angle in degrees | 0.23566 (1.9680) | |
| Intersection | Indicator for an intersection, typically signalized | 1.5287 (8.7210) | 1.5950 (7.4820) |
| Turn East | Indicator for either a south left-turn or a north right-turn lane | 0.70767 (5.4110) | 0.44039 (4.1390) |
| East Access Control | Controlled access indicator as defined by the presence of sidewalk w/o a driveway or intersection | -0.56760 (-3.1970) | |
| West Access Control | Controlled access indicator as defined by the presence of sidewalk w/o a driveway or intersection | | 0.69608 (3.3940) |
| 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) | |
| 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 | 9 | 7 |
| Number of observations | | 196 | 196 |
| Restricted Log-Likelihood | | -912.179 | -1125.113 |
| Log-Likelihood at Convergence | | -577.120 | -526.412 |

**TABLE 2 SeaTac Before and After – Mid-Block Crash Poisson Regression Models**

| Independent Variable | | Coefficient (t-stat) | |
|---|---|---|---|
| | | Before | After |
| Constant | | -1.2510 (-2.1840) | -2.6570 (-3.1400) |
| Average ADT | Average daily traffic volumes, averaged over the three year timeframe | 0.5602E-04 (4.1160) | 0.37724E-04 (1.6690) |
| Vertical Grade | Vertical grade back in % | -0.21668 (-3.4320) | -0.25822 (-2.6370) |
| Turn East | Indicator for either a south left-turn or a north right-turn lane | 0.72305 (5.3230) | 0.84039 (3.5960) |
| East Access Control | Controlled access indicator as defined by the presence of sidewalk w/o a driveway or intersection | -0.51257 (-2.8710) | |
| West Access Control | Controlled access indicator as defined by the presence of sidewalk w/o a driveway or intersection | | 0.79379 (3.2790) |
| Both Driveways | Indicator for the presence of east and west driveways within the same 50' highway section | | 1.4009 (3.9100) |
| Curb | Indicator for a curb separating lanes | -0.38982 (-2.8580) | -0.71468 (-2.2300) |
| 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) | |
| Landscaped Median | Indicator for a landscaped median of any width (4' to 12') planted with trees | | -0.71640 (-2.6840) |
| East Trees | Number of trees along the east sidewalk | | 0.30801 (2.5720) |
| Df | Degrees of freedom | 7 | 8 |
| Number of observations | | 185 | 170 |
| Restricted Log-Likelihood | | -461.026 | -199.931 |
| Log-Likelihood at Convergence | | -422.686 | -175.855 |

Each of the variables identified as statistically significant in one or more of the models above are described below in Table 3. The sign of the coefficient is interpreted, followed by a discussion of the significance of the variable.

**TABLE 3 SeaTac Crash Frequency Model Results Before and After**

| **Variable / Findings Description** | **Model(s) Before/After** |
|---|---|
| **Average ADT (daily traffic volumes averaged over three years)** | Both with and without intersections |
| A strong tendency to increase the frequency of crashes with increasing volumes | Before and after |
| Traffic volume represents the exposure to the possibility for crashes. The positive coefficients indicates that with higher traffic volumes there is likely to be a higher frequency of crashes. This is a reasonable expectation, given there are more opportunities for conflicting movements when there are more vehicles within the same time and space constraints. Thus, the probability a collision increases. | |
| **Vertical Grade Back (VGB)** | Both with and without intersections |
| A tendency to reduce crashes | Before and after |
| This variable represents the vertical slope of the roadway. The negative sign on the VGB coefficient indicates that with steeper grades there is a decreased likelihood of crashes. The grades vary between 0 and 4.3 percent with less than forty percent of the highway sections having any grade. Only 6 percent have grades greater than 3 percent. Since much of the corridor is flat one expects a greater occurrence of crashes at these locations | |
| **Intersection Indicator** | Intersection model |
| A strong tendency to increase crashes | Before and after |
| As shown in the summary statistics in the previous section's discussion, intersections have crash frequencies that combined account for anywhere from 46 to 83 percent of the crashes within the project areas. The primary reason that intersections experience significantly higher crash frequencies is that vehicles are exposed to conflicting traffic movements, which increases the probability of a collision. This research has not focused on how to address the crash occurrence at intersections, but rather to evaluate the overall safety of the roadway before and after the streetscape redevelopment projects. | |
| **Horizontal Angle** | Intersection model |
| A tendency to increase crashes at locations with greater angles | Before only |
| The angle is measured in degrees from the outside of the curve, such that small angles represent wide curves and large angles represent tight curves. Thus, the finding of a positive association between the curve angle and crash frequency follows intuitively, leading to the conclusion that more crashes occur at locations with greater curvature because of driver error. The SeaTac Phase 1 and 2 highway sections have little variation in the curvature; all sections are either straight or have a curve of one degree (to the right or left). | |
| **Turning East Indicator** | Both with and without intersections |
| A tendency to increase the frequency of crashes | Before and after |
| There are more access points along the east side of the highway, and turning movements for these access points are accommodated by left-turn lanes in the southbound direction, and some northbound right-turn lanes. The Turning East variable is a surrogate for the level of access on the east side, based on the high frequency of east turning movements compared to westward turning movements. | |
| **East Access Control Indicator** | Both with and without intersections |
| Associated with reduced crash frequencies | Before only |
| This variable represents the 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 crash frequencies indicate that locations with more control of access experience reduced crash frequencies due to less driver conflict and stops. 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 has fewer access points, and fewer sidewalks and is not significant in the Before models. | |
| **West Access Control Indicator** | Both with and without intersections |
| Associated with increased crash frequencies | After only |
| The West Access Control variable has a significant positive association with crash frequencies, indicating that locations along the west with access control experience increased crash frequencies. | |
| **Indicator of driveways on both sides of the highway** | Model excluding intersections |
| A tendency to increase the frequency of crashes | After only |
| This variable relates to level of access. Independently, the driveway variables were not significant. However, locations that have driveways on both sides of the highway have statistically significantly more crashes than locations with at most one driveway. Though these locations do not necessarily behave as four-way intersections (i.e., not all movements are allowed), they still increase the exposure to conflicting movements, and thus increase the probability of collisions. | |
| **Wide East Shoulder Indicator** | Intersection model |
| Indicator associated with reduced crash frequencies | Before only |
| The shoulder provides a space for the drivers of vehicles that leave the roadway to regain control or bring the vehicle to a stop, preferably prior to encountering a roadside hazard. Intuitively, wider shoulders free of fixed objects provide more room, and thus would be associated with fewer crashes. These variables showed that shoulders greater than 3 feet significantly reduced the frequency of crashes. | |
| **Wide West Shoulder Indicator** | Intersection model |
| Indicator associated with reduced crash frequencies | Before only |
| As noted above concerning the Wide East Shoulder variable, the shoulder provides room for errant vehicles to recover or stop without encountering fixed objects or curbs. The Wide West Shoulder variable is defined as a shoulder greater than or equal to 3 feet wide. | |
| **West Shoulder Width** | Model excluding intersections |
| A tendency to decrease crash frequency with greater widths | Before only |
| Based on the discussion of the "wide shoulder" variables above, this variable was included in the model when the intersections were excluded. The finding confirms what was expected from the findings above; that shoulders of greater width reduce crash frequency. | |
| **Bus Stop Indicator** | Model excluding intersections |
| Associated with increased crash frequencies | Before only |
| The Bus Stop variable indicates 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 experience higher crash 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 in order 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 are provided at all stop locations. | |
| **Curb Indicator** | Both with and without intersections |
| A tendency to reduce the frequency of crashes | Before and after (only in the model excluding intersections) |

| | |
|---|---|
| The Curb variable indicates where lanes are separated by a curb adjacent to the lane. Frequently this occurs along left-turn lanes, both approaching intersections and along dedicated mid-block left-turn lanes and merging lanes. The finding of a negative association between the frequency of crashes and the presence of a curb suggests that the separation of the travel lanes reduces conflicts by reducing the exposure to opposing directions of travel. | |
| **Lane Separation Indicator** | Intersection model |
| A tendency to reduce the frequency of crashes | After only |
| This variable is defined as any separation between the opposing directions of travel, including curb and landscaped medians of all widths. As suggested above concerning the Curb variable 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. | |
| **Landscaped Median Indicator** | Model excluding intersections |
| A tendency to reduce the frequency of crashes | After only |
| The Landscaped Median variable indicates the presence of median vegetation. The Curb and Landscaped Median variables were included in the non-intersection model, and both were found to be significant variables contributing to the reduction in crash frequencies. The significance of this variable confirms previous research (Phillip et al. 2004) that installing medians in place of a two-way left-turn lane reduces the frequency of crashes at mid-block locations. As suggested by the Total Trees variable, the effects of the landscaping from the effects of access control improvements are difficult separate. | |
| **Total Trees** | Intersection model |
| A tendency to reduce the frequency of crashes | After only |
| This variable represents 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 ranges from zero to eight trees per 50-foot section.<br>This finding might suggesting that the presence of trees reduces crash frequencies, and specifically the more trees the better. However, we must look more closely at the locations where trees do and don't exist. First, trees are not within higher crash location such as intersections and access points, Thus, the sections likely to have the most trees are those with fewer 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 crashes; it simply offers an explanation of why this may be the case. | |
| **East Trees** | Model excluding intersections |
| A tendency to increase the frequency of collisions | After only |
| The East Trees variable is a count variable representing the number of trees along the east shoulder within a 50-foot section. The number ranges from zero to 4 trees per section. As discussed above, the east side of the highway has more access points than the west side, and access points are typically related to increased crash frequencies.<br>Some might suggest that the East Trees variable is masking the effects of the access points (i.e., the presence of a driveway is the cause, not the trees). However, given these variables are inversely related (there are 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. Given these findings, 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 a possible contributing factor. | |

**Frequency Analysis: Comparing Before and After Conditions** The models above indicate the most significant factors affecting the frequency of crashes along the SeaTac Phase 1 and 2 project sections, both with and without intersections. The *Average ADT*, *Vertical Grade Back*, and *Turning East* variables are within all models, with coefficients that have consistent signs. In addition, at least one variable representing the separation of the directions of travel (curb, lane separation, and landscaped median) is within each model, contributing to a reduced crash frequency.

The variables that change from the Before to the After conditions are the variables relating to mid-block access control (*East Access Control* and *West Access Control*). Before the redevelopment, the access control along the east side of the highway tended to decrease the frequency of crashes. Given most of the highway does not have sidewalk controlling the access, this finding indicates the access control may play a particularly significant role in reducing crash frequencies. However, in the After conditions, the *West Access Control* variable is significant in both models, associated with an increase in crash frequencies.

The *Bus Stop* indicator variable was significant in the Before model of mid-block locations, contributing to an increase in the frequency of crashes. The fact that this variable is not significant in the After conditions, indicates that there has been a probable improvement in the safety at bus stop locations. As noted above, improvements at bus stop locations that were part of the redevelopment projects include bus pullouts (which are curbside lanes added at bus stops that allows transit vehicles to pull out of the through travel lanes while they load and unload passengers) and better 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 the width of shoulders are significant in the Before models. Following the redevelopment, the shoulders were narrowed to 1-2 feet along most of the project section, in order to allow for the 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. Thus, there was not sufficient variation in these variables 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 these variables were included in the Before model instead of the *Wide Shoulder* variables, they significantly contributed to increased crash frequencies (the *Wide Shoulder* variables were included in the final model based on the chi-square statistic). We can conclude that there is a probable increase in crashes in the After conditions based on the narrow shoulder width.

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

*Injury Severity Models*

Crash injury severity models were developed using the multinomial logit (MNL) method. The injury severities were split into three discrete choice categories, following the structure laid out by Holdridge et al. (*8*) and Shankar et al. (*9*). This structure consists of three categories: property damage only (PDO), injury crashes (evident, disabling, and fatal injuries), and possible injuries. One of the limitations in the data that lead to this structure is the low frequency of fatal and disabling injury crashes. By combining all injury levels there are sufficient data to estimate coefficients.

**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 determinants of crash injury severities. The model results are presented in Table 4.

**TABLE 4 SeaTac Before and After – Crash Injury Severity Utility Functions**

| | Before Coefficient (t-stat) | | | After Coefficient (t-stat) | | |
|---|---|---|---|---|---|---|
| Variable | 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 crash | -1.0439 (-4.989) | | | | | |
| Rear end crash at an intersection | | | | | 0.6612 (1.610) | |
| Opposite direction crash | | 1.1584 (2.569) | | | 2.1901 (5.493) | |
| Same direction sideswipe crash | 0.9781 (2.470) | | | 1.1028 (2.851) | | |
| Crash with only one car | 2.1310 (2.231) | | 2.9290 (3.012) | -1.0264 (-1.985) | | |
| Crash 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 crash involving at least one driver over 65 | | 1.4334 (2.629) | | | 2.3359 (2.991) | |
| DUI crash between 7pm and 5am | | | | 2.6454 (2.534) | | 3.1213 (2.881) |
| Crash occurred between 7pm and 5am | 0.5226 (2.457) | | | | | |
| Crash 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) | |
| Crash 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 Hausman test for the independence of irrelevant alternatives (IIA) indicates if there are any shared unobserved variables between the injury severity categories used in these models. However, when the test was performed the models failed to converge, indicating that the Hessian is non-positive definite at the start value.

The overall probabilities of each injury-severity category are presented at the end of Table 4. These probabilities, represented as the percent of all crashes that are expected to result in each injury-severity level, show an increase in the probability of injury crashes, and a decrease in the probability of possible injuries. Property-damage crashes are 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. The significance of the individual variables and the signs of the coefficients are discussed in Table 5.

**TABLE 5 SeaTac Before and After – Crash Injury Severity Variables and Findings**

<table>
<tr><th>Variable</th><th>Findings</th><th>Utility Function(s)</th></tr>
<tr><td>Rear End Crash</td><td>A tendency to decrease the probability of PDO crashes in the Before conditions</td><td>PDO (before)</td></tr>
<tr><td colspan="3">The occurrence of a rear end crash tends to result in more damage than to property only, i.e. some type of injury (though in this model rear end crashes were not significant in increasing injury or possible injury crashes). In the Before conditions, rear end crashes occur at intersections and mid-block locations, while in the After conditions, the rear end crashes are concentrated at the intersections, as discussed below.</td></tr>
<tr><td>Rear End Crash at Intersection</td><td>A tendency to increase the probability of injury in the After conditions</td><td>Injury (after)</td></tr>
<tr><td colspan="3">In the Before conditions the occurrence of a rear end crash was associated with reduced property damage, while in the After conditions it is associated with an increase in injuries when the rear-end crash occurred at an intersection. This may be related to changes in the locations of rear-end crashes.</td></tr>
<tr><td>Opposite Direction Crash</td><td>A tendency to increase the probability of injuries in the Before and After conditions</td><td>Injury (before and after)</td></tr>
<tr><td colspan="3">A collision that involves vehicles traveling in opposite directions is associated with an increased probability for injuries. The closing speed in these crashes is likely to be greater than in many same-direction crashes, which results in greater deceleration upon impact and greater forces on the individuals in the vehicles.</td></tr>
<tr><td>Same Direction Sideswipe</td><td>A tendency to increase the probability of PDO crashes in the Before and After conditions</td><td>PDO (before and after)</td></tr>
<tr><td colspan="3">This variable is associated with an increased probability for property damage. The split in sideswipe crash between those that occur in the same direction, and those that occur in opposite directions produced a significant result – that is, when combined Sideswipes contributed to decreased Possible Injury crashes, but when separated the Same Direction Sideswipes resulted in increased PDO and the opposite direction variable dropped out. When vehicles collide in a sideswipe -type collision there is less direct impact. The lesser force transferred to the drivers reduces their probability of sustaining injuries.</td></tr>
<tr><td>Crash with one car</td><td>A tendency to increase the probability of PDO and Possible Injury crashes in the Before conditions, and decrease PDO crashes in the After conditions</td><td>PDO (before),<br>Possible Injury (after)</td></tr>
<tr><td colspan="3">Single-vehicle collisions are associated with increased PDO and Possible Injury probability in the Before conditions, and a reduced PDO probability in the After conditions. This change may indicate that the severity of single-vehicle collisions decreased following the completing of the streetscape projects. This follows from the analysis of the fixed-object collision injury severity in the sections above, in which it was illustrated that the severity of fixed-object collisions (a sub-set of single-vehicle collisions) was lowered.</td></tr>
<tr><td>Crash with more than two cars</td><td>A tendency to increase the probability of injuries in the Before and After conditions</td><td>Injury (before and after)</td></tr>
<tr><td colspan="3">The Multiple Vehicle variable is 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 within the collision dynamics.</td></tr>
<tr><td>At least one pedestrian or bicyclist involved</td><td>A tendency to increase the probability of injuries in the Before and After conditions</td><td>Injury (before and after)</td></tr>
</table>

<table>
<tr><td colspan="3">As noted above in the comparative description of crashes within the project areas, pedestrians and bicyclists are often the individuals most severely injured in collisions. Pedestrians and bicyclists sustained eleven of the twenty-seven fatal or disabling injuries. The variable that indicates at least one individual involved in the collision was not in a motorized vehicle is associated with an increased probability of injury.</td></tr>
<tr><td>DUI crash involving at lease one driver over 65 years old</td><td>A tendency to increase the probability of injuries in the Before and After conditions</td><td>Injury (before and after)</td></tr>
<tr><td colspan="3">This interaction between age and sobriety in a collision is such that collisions involving at least one driver under the influence of alcohol, and at least one driver over the age of 65 increase the probability of an injury. The interaction is likely related to the increased vulnerability of injury in older individuals. This does not imply that the driver who was over 65 was the one under the influence.</td></tr>
<tr><td>DUI crash occurring between 7pm and 5am</td><td>A tendency to increase the probability of PDO and possible injury in the After conditions</td><td>PDO, Possible Injury (after)</td></tr>
<tr><td colspan="3">The interaction between the hours of darkness and a driver under the influence of alcohol is related to an increased probability of property damage or possible injury crashes. Given approximately 71% of DUI crashes in the After conditions occur during the night hours, the traffic volumes are less than during the peak periods or mid-day. Thus, though most of the crashes occur during this timeframe, they likely have fewer multi-vehicle collisions, which have been shown to increase the probability of injury. Thus, increased PDO and possible injury crashes are justified.</td></tr>
<tr><td>Night Crash - between 7pm and 5am</td><td>A tendency to increase the probability of PDO crashes in the Before conditions</td><td>PDO (before)</td></tr>
<tr><td colspan="3">As noted above, the traffic volumes are lower during the night hours, thus reducing the exposure to other vehicles. Collisions occurring in the night hours are more likely to result in property damage only, than collisions at other times of day (all else being equal).</td></tr>
<tr><td>Crash occurred on a wet road between 7pm and 5am</td><td>A tendency to increase the probability of injury in the Before conditions</td><td>Injury (before)</td></tr>
<tr><td colspan="3">The interaction between the night conditions and wet roadways results in an increased probability of injury – i.e., a collision that occurs at night on a wet road is more likely to result in an injury, than either on a dry road or during the day. This variable represents a subset of the Night Crash variable discussed above, and yet they are both significant in the same model of the Before conditions. The combined effects of reduced visibility at night and possibly with rain and glare, and the wet pavement are likely to contribute to 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 the wet pavement. Higher closing speeds are likely, resulting in greater injury.</td></tr>
<tr><td>One or more drivers at least partially ejected from a vehicle</td><td>A tendency to increase the probability of injury in the Before conditions</td><td>Injury (before)</td></tr>
<tr><td colspan="3">The Ejection indicator variable is defined as 1 if any driver is partially or fully ejected from a vehicle, and 0 otherwise. In all, 15 crashes involved ejected drivers, all in the Before conditions. Ejection indicates 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 crash.</td></tr>
<tr><td>Lane Separation</td><td>A tendency to decrease the probability of injuries in the Before conditions, and increase the probability of injuries in the After conditions</td><td>Injury (before and after)</td></tr>
<tr><td colspan="3">The Lane Separation indicator variable is defined as 1 for any location that has a curb or a median of any width, including landscaped medians. In the Before conditions, this variable is associated with a reduced probability of an injury. This is likely the case given curbs are typically installed at potentially high-conflict points such as along turn lanes, in order to reduce conflicts that occur near access points. The injuries likely in the conflicts that are avoided are avoided as well.</td></tr>
</table>

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<tr><td colspan="3">In the After conditions, 97 percent of the mid-block sections have some type of lane separation. However, only 20 percent of the After crashes occurred at locations with lanes separated by a curb or median. One possible explanation for the tendency of the Lane Separation variable to increase the probability of injuries is that it does indicate there is a median or curb within the roadway resulting in crashes where lifting or redirecting the vehicle may occur</td></tr>
<tr><td>Crash involving at least one fixed object</td><td>A tendency to increase the probability of injury in the Before conditions and decrease the probability of a possible injury in the After conditions</td><td>Injury (before), Possible Injury (after)</td></tr>
<tr><td colspan="3">Colliding with a fixed object in the Before conditions tends to increase the probability of injuries. Following the completion of the streetscape projects, the Fixed-Object variable is associated with a reduction in Possible Injury crashes. Based on the descriptive analysis of the collisions with fixed objects in the sections above, this is not unexpected at this point in time. However, as the trees grow there is the possibility that they will reach the size where they behave more like other fixed objects that existed in the roadside environment prior to construction such as utility poles.</td></tr>
<tr><td>Number of trees on west side of road</td><td>A tendency to increase the probability of PDO crashes in the After conditions</td><td>PDO (after)</td></tr>
<tr><td colspan="3">As noted above, trees affect the frequency of crashes, and here we see that they likewise affect the severity of crashes. Planting trees along the west side of the roadway has evidently had the effect of increasing the probability of property-damage crashes. Given the relatively small size of the trees during the analysis timeframe, this finding suggests that interactions with trees are not severe. However, the concern is that as the trees grow larger, the severity of these interactions may increase significantly.</td></tr>
</table>

## FUTURE RESEARCH AND CONCLUSIONS

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

The In-Service Evaluation of Landscaped Medians will extend at least an additional five years, to 2010, in order to collect data from additional cities implementing similar streetscape redevelopment projects. Collecting data from these project areas will likely increase the variation in some variables (such as number of lanes, median type, frequency/spacing of trees, etc), which may shed light on additional effects and interactions of variables. Varied median designs and features will allow for a comparison 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.

The long-term impacts of trees within the Design Clear Zone on an urban principle arterial are of concern. The SeaTac Phase 1 and 2 projects were completed close to 10 years ago, so additional data are 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 Landscaped Medians indicates a three-year analysis timeframe should be used, and 2) because of serial correlation issues based on multiple crash counts at the same location (one count per year) that 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.

Additional research that investigates 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 impacting the outcomes in the current study. Ideally, the study would entail a 4-6 lane divided highway with medians, mid-block turn pockets, and sidewalks in the existing conditions, in which the project is simply to install landscaping within the median and along the roadside.

**Conclusions**
This analysis shows that initially SR 99 was a high-crash corridor compared to other similarly classified highway facilities in Washington State. Following the construction of the streetscape projects, SR 99 is still a high-crash corridor, though the crash rate on the combined projects decreased. The increase in the crash rate on the Phase 2 project indicates that the results based on the frequency of crashes are mixed.

Overall the locations of crashes shifted significantly. Before the projects were constructed more of the crashes occurred at mid-block locations than following construction. This result was expected, given the extent of the turning movement restrictions imposed by the medians. The U-turn crashes subsequently increased following the projects' construction, increasing from 4 crashes to 35 within three years. These changes related directly to the access control effects of the medians.

The crash 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 crashes, whereas bus stops, some turn lanes, intersections, and horizontal curves tended to increase the number of crashes. The most significant contributing factors to increasing crash 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 crashes, and some access control measures tend to increase crashes.

Interestingly, tree variables had relatively little impact on the prediction of crash rates. In one case the number of trees was found to be statistically significant in decreasing crash 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 crash rates. In one other case, the presence of trees in association along mid-block sections slightly increased crash rates. It is possible that the presence of trees caused some loss of visibility and thus increased crash potential, but it is also possible that in this case, the tree variable was acting as a surrogate for some 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 crashes occur and the involved motorists do not report those crashes.) 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 a crash being a "property damage only" crash (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 crash severity may increase. While the tree 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 crashes along the corridor to ensure that crash 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 crashes decreased following construction of the Phase 1 and Phase 2 projects. Given the low number of crashes 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 (*10*). 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 crash rate and the shift in crash 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.

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