An Assessment of Interstate Safety Investment Priorities in Washington State

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16. Abstract

The Washington State Department of Transportation (WSDOT) commissioned the current study, targeting the entire interstate mainline network in Washington State, to provide strategic direction to multi-biennial investment interstate locations that offer the greatest return in terms of cumulative and annualized safety benefits. The objectives of this study were to prioritize interstate locations strategically in terms of risk of high social cost, while targeting locations that repeat in nature. As such, the methodological questions that arise relate to the following: what measurements are required to comprehensively address the "strategic risk evaluation" aspect, and what measurements are required to adequately address the "repeat location identification" aspect. Using a step-wise procedure to systematically assess mainline interstate accident risk, a multi-objective approach was employed in order to factor in multiple criteria for ranking of segments, while accounting for multiple accident types as inputs in the ranking process. The planned scope of this study produced a target priority list of 202 locations with a total length of 154.5 miles. This list should be evaluated in detail for scoping improvements, associated costs and benefits prior to evaluating locations in the "tracking list." The next step in ensuring implementation and successful deployment of this procedure will be to carefully evaluate cost improvement strategies and estimate associated benefits. Once costs and benefits are computed, one can systematically proceed to evaluate various measures of cost efficiency and effectiveness using lifecycle and annualized benefits and costs.

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Introduction

The Washington State Department of Transportation (WSDOT) embarked on a statewide traffic safety initiative in the early 1990s to enable the systematic assessment and treatment of accident risk on state highways. The initial effort was targeted at roadway segments on a sample of the entire state highway system for which risk models were developed and tested (Milton and Mannering 1998). The models were statistical in nature and provided a framework for estimates of overall accident risk. The structure of the models was similar to that employed in early accident modeling work by Shankar et al. (1995) in the analysis of safety risk on Interstate 90 near Snoqualmie Pass. In the 1995 study, Shankar laid out the foundation for modeling both frequency- and severity-oriented risks. The 1998 models from the Milton study applied the frequency framework to segment accident risk. These models were supplemented with a roadside accident risk framework that enabled the estimation of run-off-the-road accidents. Around 1997, about five years since the inception of the statewide safety assessment initiative, a targeted effort involving the refinement of statistical models for roadway segments was conducted (Shankar et al. 1997). Complementing this advanced effort was an attempt undertaken by the WSDOT Design Policy and Standards branch to quantify the risk of median crossovers on state highways (Shankar et al. 1998; Albin et al. 2001; Glad et al. 2002; Chayanan et al. 2004). At the turn of the century, efforts continued in the area of severity modeling, which WSDOT viewed as an important step in the development of a systematic process. Initial testing of severity-oriented models was based on early work by Shankar et al. (1996) that analyzed severity risk under inclement conditions on Interstate 90 near Snoqualmie Pass. Other studies conducted by WSDOT safety researchers targeted non-motorized modes such as pedestrian travel. In a study published in 2003, Shankar et al. provided a statistical framework for the analysis of mid-block pedestrian accident risk, and complemented this effort by examining the risk of pedestrian severity in a subsequent study published in 2006. Milton et al.

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(2008) concurrently applied a state-of-the-art statistical framework to assess the risk of frequency and severity simultaneously. In a paper published in 2008, Milton et al. laid out the foundation for the analysis of segment and intersection accident severity proportions. This study was meant to provide a methodological completeness to the study of high accident locations and corridors (HAL, HAC) and pedestrian accident locations (PAL), long established in WSDOT practice as the three basic modalities of network safety analysis.

The above-described studies provided utility in the forecasting of accident risk – they employed historical data related to accident frequency, severity, roadway geometrics, and weather data and estimated, for example, the mean number of accidents expected for a given segment, intersection, or corridor. As such, prioritizing locations was entirely pro-active in the sense that "locations of interest" were ranked in terms of expected frequency and severity risk. This in itself was a process subject to some uncertainty, as forecasting accuracy is a function of uncertainty in input values, missing data, and uncertainty in the models themselves. In addition, forecasting accuracy in great part depended on the length of accident history, roadway geometry, and weather-related information. It should be noted here that around the year 2005, a systematic effort was undertaken by WSDOT to gather roadside inventories. The factors mentioned above imply significant testing and refinement of models over a length of time as more precisely measured roadside data became available. In the meantime, the need remains to prioritize locations in terms of some measure of "safety need." To this end, WSDOT's well-established accident database (MARS and its current variants run by the Transportation Data Office) proved to be of great utility. While this database is entirely historical in nature and subject to reporting biases (missing accident reports due to low severity), the vast amount of accident-specific information for over 50,000 accidents reported annually served as a prime resource for longitudinal analysis of safety. The TDO also maintains digitally compiled alignment data and traffic volume data for the entire

state highway network. Given this rich informational base, a methodology that provided for the ability to target repeat locations resulting in high societal cost seemed possible. Shankar et al. (2005) tested a data envelopment analysis based method to a sample of high accident locations and used the prioritized list to forecast accident risk for future biennia. The study reported that the data envelopment approach is reasonably robust for repeat locations (locations with non-zero accident histories at least standard deviation above the accident mean). In addition, forecasting accuracy was substantial for the HAL sample tested. Nearly three quarters of the sampled locations were forecasted at accident levels within 10 percent of the observed historical count.

Goals and Objectives

Given the promise of this method, the WSDOT commissioned the current study targeting the interstate network in the state. The motivation was to provide strategic direction to multi-biennial investment in interstate locations that offer the greatest return in terms of cumulative and annualized safety benefits. The specific goals and objectives of this study were to prioritize interstate locations strategically in terms of risk of high social cost, while targeting locations that repeat in nature. As such, the methodological questions that arose related to the following: what measurements are required to comprehensively address the "strategic risk evaluation" aspect, and what measurements are required to adequately address the "repeat location identification" aspect? Measurements here relate to the accident severity and frequency, as well as geometric and weather information. The 2005 Shankar report suggested that reasonable forecasting accuracy can be achieved with commonly available geometric information such as number of lanes, number of horizontal and vertical curves in a segment, shoulder widths, number of interchanges and overpasses, presence of medians, and average daily traffic volumes. In addition, the report suggested that several factors relating to accident outcomes be used for comprehensive safety

coverage. For example, assessing safety risk in terms of total societal cost, per-accident societal cost, total severity index, per-accident severity index, total frequency, frequency of fatalities, and frequency of disabling injuries would provide for a multi-objective approach. Such an approach also has significant potential for a robust identification of priority locations, since it is based on total and unit-level, that is, segment-level and per-accident measurements.

Scope of the Study

The entire interstate mainline network is examined in this report. No ramp segments are analyzed. Comprised of 1,528 centerline miles, and covering all six regions, the study examines interstates 5, 405, 90, 205, 705, 82, and 182. Interstate 5 spans more than 276 centerline miles, with average daily traffic volumes in excess of 290,000 in the Seattle area. Over 25,095 accidents were reported on the Interstate 5 mainline for the period 2002-2006, with 15,560 property damage accidents, 7,047 possible injury accidents, 2,012 evident injury accidents, 358 disabling injury accidents, and 118 fatal accidents. Out of the 25,095 accidents, 4,872 were single-vehicle, 15,105 were two-vehicle, 3,842 were three-vehicle, 968 were four-vehicle, and 308 were accidents involving five vehicles or more. In addition, it is noted that 14,259 accidents were of the rear-end type, 3,973 of the sideswipe type, 1,205 of the same direction type, 3,807 of the fixed-object type, 590 of the overturn type, 33 of the head-on type, and 1,228 representing other types combined.

Interstate 405 spans roughly 30 centerline miles, with average daily traffic volumes in excess of 200,000 in the Bellevue area. Over 7,070 accidents were reported on the Interstate 405 mainline for the period 2002-2006, with 4,444 property damage accidents, 2,204 possible injury accidents, 350 evident injury accidents, 62 disabling injury accidents, and 10 fatal accidents. Out of the 7,070 accidents, 860 were

single-vehicle, 4,697 two-vehicle, 1,177 were three-vehicle, 256 were four-vehicle, and 80 were accidents involving five vehicles or more. In addition, it is noted that 4,828 accidents were of the rear-end type, 984 of the sideswipe type, 268 of the same direction type, 765 of the fixed-object type, 72 of the overturn type, 2 of the head-on type, and 151 representing other types combined.

Interstate 90 spans roughly 297 centerline miles, with average daily traffic volumes in excess of 150,000 in the Bellevue-Seattle area. Over 3,295 accidents were reported on the Interstate 90 mainline for the period 2002-2006, with 1,762 property damage accidents, 496 possible injury accidents, 785 evident injury accidents, 188 disabling injury accidents, and 64 fatal accidents. Out of the 3,295 accidents, 1,948 were single-vehicle, 1,132 were two-vehicle, 158 were three-vehicle, 34 were four-vehicle, and 23 were accidents involving five vehicles or more. In addition, it is noted that 633 accidents were of the rear-end type, 281 of the sideswipe type, 227 of the same direction type, 1,098 of the fixed object type, 618 of the overturn type, 6 of the head-on type, and 432 representing other types combined.

Interstate 205 spans roughly 11 centerline miles, with average daily traffic volumes in excess of 135,000 in the Clark County area near the state border with Oregon. Over 377 accidents were reported on the Interstate 205 mainline for the period 2002-2006, with 234 property damage accidents, 105 possible injury accidents, 28 evident injury accidents, 4 disabling injury accidents, and 6 fatal accidents. Out of the 377 accidents, 96 were single-vehicle, 233 were two-vehicle, 41 were three-vehicle, 7 were four-vehicle, and 0 were accidents involving five vehicles or more. In addition, it is noted that 177 accidents were of the rear-end type, 64 of the sideswipe type, 27 of the same direction type, 66 of the fixed-object type, 23 of the overturn type, 0 of the head-on type, and 20 representing other types combined.

Interstate 705 spans roughly 1.5 centerline miles located in Pierce County, with average daily traffic volumes in excess of 50,000. Over 88 accidents were reported on the Interstate 705 mainline for the period 2002-2006, with 38 property damage accidents, 30 possible injury accidents, 18 evident injury accidents, 2 disabling injury accidents, and 0 fatal accidents. Out of the 88 accidents, 35 were single-vehicle, 36 were two-vehicle, 13 were three-vehicle, 4 were four-vehicle, and 0 were accidents involving five vehicles or more. In addition, it is noted that 40 accidents were of the rear-end type, 9 of the sideswipe type, 1 of the same direction type, 31 of the fixed-object type, 2 of the overturn type, 2 of the head-on type, and 3 representing other types combined.

Interstate 82 spans roughly 133 centerline miles, with average daily traffic volumes in excess of 45,000 in the Yakima area. Over 620 accidents were reported on the Interstate 82 mainline for the period 2002-2006, with 202 property damage accidents, 39 possible injury accidents, 259 evident injury accidents, 80 disabling injury accidents, and 40 fatal accidents. Out of the 620 accidents, 424 were single-vehicle, 182 two-vehicle, 14 were three-vehicle, 0 were four-vehicle, and 0 were accidents involving five vehicles or more. In addition, it is noted that 84 accidents were of the rear-end type, 42 of the sideswipe type, 19 of the same direction type, 119 of the fixed-object type, 266 of the overturn type, 7 of the head-on type, and 83 representing other types combined.

Interstate 182 spans roughly 15 centerline miles, with average daily traffic volumes in excess of 40,000 in the Benton County area. Over 140 accidents were reported on the Interstate 182 mainline for the period 2002-2006, with 80 property damage accidents, 12 possible injury accidents, 30 evident injury accidents, 16 disabling injury accidents, and 2 fatal accidents. Out of the 140 accidents, 65 were single-vehicle, 65 two-vehicle, 9 were three-vehicle, 1 was four-vehicle, and 0 were accidents involving five vehicles or more. In addition, it is noted that 40 accidents were of the rear-end type, 14 of the

sideswipe type, 12 of the same direction type, 14 of the fixed-object type, 30 of the overturn type, 0 of the head-on type, and 30 representing other types combined. Figure 1 shows the distribution of accidents on the various interstates. In particular, the accident types and severities mentioned previously are shown for the period 2002-2006.
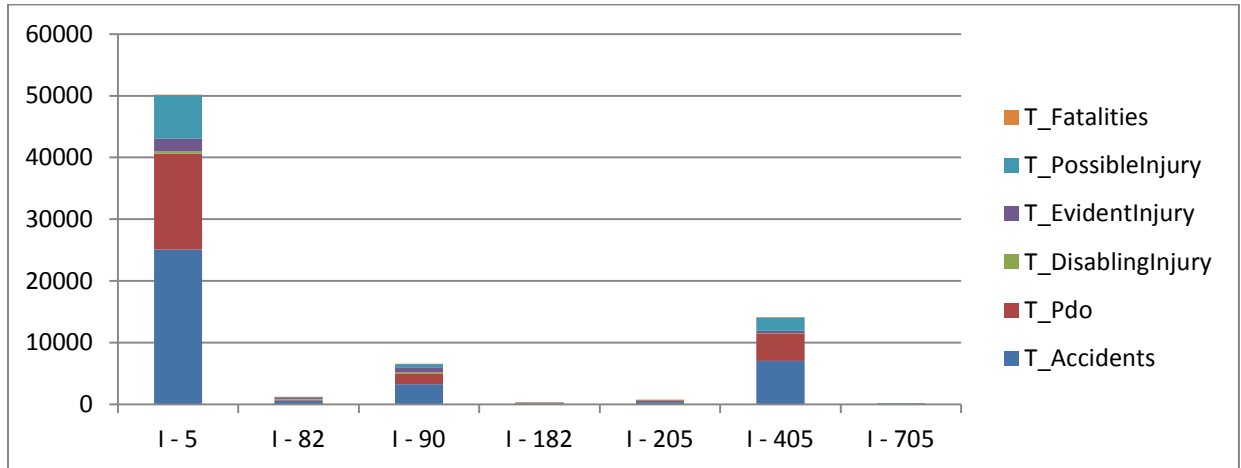

	All Accidents	PDO	Disabling	Evident	Possible	Fatalities
I - 5	25,095	15,560	358	2012	7,047	118
I - 82	620	202	80	259	39	40
I - 90	3,295	1,762	188	785	496	64
I - 182	140	80	16	30	12	2
I - 205	377	234	4	28	105	6
I - 405	7,070	4,444	62	350	2,204	10
I - 705	88	38	2	18	30	0

Figure 1. Accident Distribution Across the Seven Interstates in Washington State in 2002-2006.

Study Methodology

Given the above-mentioned empirical setting, a five-step procedure was adopted in the development of network safety priority locations. In the first step, the network was screened and segmented. In step

two, the segments were evaluated in terms of accident-related measurements such as total societal

cost, per-accident societal cost, total severity index, per-accident severity index, fatal and injury counts,

as well as total accident frequency. These measurements were made for the five year period 2002-2006

based on WSDOT-provided mainline accident reports. In step three, the calculated segment-specific

measurements were assessed in a multiobjective manner by relating them to various inputs such as

collision types and vehicle involvement. In all, 12 accident type inputs in the form of frequencies were

used – namely, rear-end, same direction, sideswipe, head-on, fixed object, overturn, other collision type,

single vehicle, two-vehicle, three-vehicle, four-vehicle, and five-vehicle counts. In step four, the inputs

were assessed using the data envelopment approach to determine the relative ranking of the segments

and associated priority within the interstate network as a whole.   In step five, based on the

determination in step four, improvement needs were identified. The improvements were not costed,

however, nor were the estimated benefits from the targeted reductions determined in step four. Each

of the above-mentioned steps is described in some detail in the following discussion.

Safety priority evaluation process step one: screening and segmenting the network

Since a multiobjective foundation is required for the systematic assessment of safety risk, the network is

screened on the basis of spatial distribution of accident counts. Using the adjusted route milepost

locator, every reported milepost in the accident database for the period 2002-2006 was screened for

cumulative accident counts. Theoretically, if an accident is reported at every single milepost marker

(i.e., every one hundredth of a mile), the interstate network can be broken down into 152,800 0.01-mile

segments. While being a computationally burdensome task, this level of segmentation is prone to

aggregation biases in terms or risk extrapolation to longer segments. It was hence decided that network

segmentation would be conducted on the basis of accident count clusters. Using mathematically proven

techniques to identify robust spatial clusters, the entire interstate network was evaluated by direction. This type of segmentation has the advantage in that it relies on the notion of grouping accident locations using a clustering statistic applied uniformly to all locations. This statistic is usually defined in terms of the Euclidean distance between accident locations and a cluster "mediod," a physical object located at the center of the cluster. This clustering procedure was conducted independently for each of the interstates. The independent clustering approach was adopted for the primary reason that accidents on roadway segments are essentially linearly represented. As a result of this clustering procedure, 11,447 segments resulted. The distance between adjacent clusters was tagged as a zero-accident segment. It should be noted here that the segments are not of uniform length. Out of the 11,447 segments, 7,070 were non-zero accident segments with a mean length of 0.17 miles (1,213.27 total), and 4,377 were zero-accident segments with a mean length of 0.07 (315.27 total) miles.

Safety priority evaluation process step two: defining accident-based prioritization criteria

Using the clustering-based segments as units of analysis, total societal cost, per-accident societal cost, total severity index, per-accident severity index, total accident frequency, fatal and injury frequencies were determined for each of the segments. The first four criteria were used to run a first-level filter on above-average segments. For example, segment "I" was compared in terms of its computed values for the cost and societal index criteria against the mean values for all segments for a particular interstate. If segment "I" was at least one standard deviation in excess of the mean, it was flagged with respect to that criterion. In this manner, theoretically, a segment can be tagged with four flags. The total accident frequency and fatal/injury frequency were not used in the strictest sense as flagging criteria; rather, they were used as lower bounds for ensuring that flagged segments had at least one non-zero fatal/injury outcome. The total frequency criterion was used to break ties between segments if two

segments were ranked the same. The segment with the higher frequency total was given priority. Of

particular interest in this step is the assumption that segments were to be flagged on the basis of

interstate-specific criterion means. As opposed to comparing segments across interstates by using the

overall interstate mean, comparison is confined to the family of segments within a particular interstate

for the primary reason that interstates have substantial heterogeneity in spite of being in the same

functional class. It can also be argued that interstate 5 may have a different safety performance

function compared to interstate 405, or for that matter another interstate.

In the process of flagging segments, no particular segment was tagged with more than three flags. Out

of the 7,070 non-zero accident segments, 1,781 segments were tagged with at least one flag. However

no segment in the sub-population of 1,781 non-zero accident locations met all four criteria. In total, 411

segments were tagged with three flags, while 322 segments were tagged with two flags, and 1,048

segments with one flag. At the end of step two, the original network of 11,447 segments was trimmed

down to 1,781 segments. Various inputs relating to accident types were then computed for the

segments in order to apply the data envelopment analysis procedure. At this point it should be noted

that the 1,781 segments constitute what can be called a "starting priority list."

Safety priority evaluation process step three: computing segment-specific inputs

Using geometric alignment, ADT, and accident-specific information provided by WSDOT, various inputs

were computed for each of the 11,447 segments. Although, only 1,781 segments were evaluated for

the purpose of ranking and prioritization, inputs were computed for all segments. Geometric inputs for

zero-accident segments can later be utilized for forecasting purposes if necessary. For zero-accident

segments, inputs were restricted to ADT and geometrics, whereas accident-specific information relating

to collision type and vehicle involvement was added as input for non-zero accident segments. As mentioned previously, 12 accident related inputs were computed – rear-end, same direction, sideswipe, head-on, fixed object, overturn, other collision type, single-vehicle, two-vehicle, three-vehicle, four-vehicle, and five-vehicle counts. Geometric inputs were computed in terms of interchange and overpass frequency, average, maximum, and minimum number of lanes in cross section, average, maximum, and minimum shoulder widths, number of horizontal and vertical curves and average, maximum, and minimum ADT.

Safety priority evaluation process step four: prioritizing and estimating accident reduction targets

The data envelopment analysis (DEA) procedure was applied in this step to identify segments as candidates for improvements. The DEA approach relies on the notion that a set of inputs produces a set of outputs with perfect efficiency. Any set of inputs that uses excesses can then be viewed as unproductive; in the safety case, they can be viewed as segments that encounter more accidents than they should. The underlying assumption in this approach is that accidents are unavoidable; however, if one can identify the optimum for a given location, any "excess accident" occurrence can then be evaluated appropriately in terms of improvement need by ranking the segments in descending order. In the current study, since the 12 accident inputs are available from step four, they were evaluated to determine segments where excess accident occurrence took place in the period 2002-2006. These excesses are termed "slacks" in DEA terminology. Segments were then ranked in descending priority based on a determination of slacks on a location-specific basis. The slacks also represent the desirable reduction in the input. The advantage of this approach is that targets are now determined on a location-specific basis, and not as a general system-level mean threshold alone. A system-level mean threshold is useful if it is determined through aggregation of location-specific thresholds. However, any

number of location-specific threshold combinations can result in an arbitrarily chosen system level threshold. This is a primary reason why the DEA procedure is appealing – not only does it allow for segment-specific targets; the reduction targets can be multidimensional (as in all 12 accidents theoretically decreasing), so that improvement strategies can be identified based on the types of accidents that require reduction. A total of 1,213 segments were determined to have excess accidents, with an average targeted reduction of 28.77 accidents per segment. This is a target estimate for a 5-year period. Hence, on an annual basis, the mean targeted reduction in accident frequency is 5.76. Of the 1,213 segments, 188 segments called for reductions in roadside-related accidents such as fixed objects and overturns, while 506 segments called for reductions in rear-ends. Sideswipe reduction segments numbered 411, while 1 segment required head-on targets, 302 segments required same direction, and 225 segments required other collision type reductions. This list of targeted segments was provided to WSDOT earlier and is not included in this report. What is useful from this prioritization process is that rankings can be assigned on the basis of the types of reductions. A priority-one location is defined as a location where head-on, fixed-object, and overturn accident targets are recommended. A priority-two location is defined as a location where reduction targets are primarily for multi-vehicle accident locations. A priority-three location is defined as a location primarily tagged as a "tracking location of interest." That is, these are locations where reduction targets are not recommended; however, for the purpose of future tracking due to potentially greater-than-expected growth in accident profiles, they are tagged to provide proactive guidance.

Based on the targeted reductions, a revised estimate of segment-specific costs and severity indexes can be computed. This estimate can be viewed as the optimal cost-severity profile for the interstate system when aggregated across all non-zero segments. This is a highly computationally intensive process due to the large number of segments, and the fact that the objective function is multidimensional (total

societal cost, per-accident societal cost, total severity index, and per-accident severity index), run times can exceed several hours, with no guarantee of convergence. Initial tests suggest a scenario where total societal cost is likely to decrease system-wide, while there may be a marginal increase in per-accident societal cost. This is to be expected, since targeted reductions substantially reduce the denominator in per-accident cost computations.

Safety priority evaluation process step five: determining improvement strategies

Improvement strategies were independently identified based on the targeted accident type. For example, if segment "I" was targeted for fixed-object reduction, then one possible countermeasure is to reduce horizontal curvature if the fixed object on the roadside is not removable or outside the clear zone. Some complexity remains in the identification of improvement strategies. For example, due to reporting inaccuracies, segments with recommended reductions do not appear to have geometric attributes suitable for treatment. For example, in certain point or near-point locations (less than 0.05 miles in length), a recommended reduction might focus on fixed-object accidents. The SRView log, however, may show any fixed objects suitable for treatment within the milepost limits stated for the segment. In such cases, improvement strategies have to be viewed in a longer window. As such, the draft list of improvement strategies is premature; upon further examination and conferral with WSDOT staff, it is hoped that a realistic set of strategies can be identified accounting for reporting errors and most likely cause.

Conclusions and Recommendations

A step-wise procedure to systematically assess mainline interstate accident risk was presented in this study. This procedure is summarized in Figure 2. A multi-objective approach was employed in order to factor in multiple criteria for ranking of segments, while accounting for multiple accident types as inputs in the ranking process. A data envelopment analysis procedure was used to rank segments on the basis of excess accidents reported in the 5-year period 2002-2006. Segments were defined on the basis of accident count clusters and flagged in importance of severity criteria based on interstate specific averages. This maintained a consistent baseline within an interstate for comparing segments. However, during the overall ranking process, all interstate segments with non-zero accident histories were evaluated simultaneously to determine segment priorities. The data envelopment analysis procedure was useful in the identification of reduction targets for specific accident types, segment by segment. Using this reduction target as a desirable scenario, an estimate of overall safety improvement in terms of societal cost and severity was computed. The reduction targets were also used in the identification of improvement strategies for each candidate segment.

It was determined that out of a total of 1,528 bi-directional centerline miles of interstate network, a total of 41 locations were rated priority one with a total length of 51.07 centerline directional miles and a mean length of 1.25 miles. All of these locations required at least one recommended reduction in head-on, fixed-object or overturn collisions. This targeted network length represents 3.34 percent of the entire interstate mainline in Washington State.
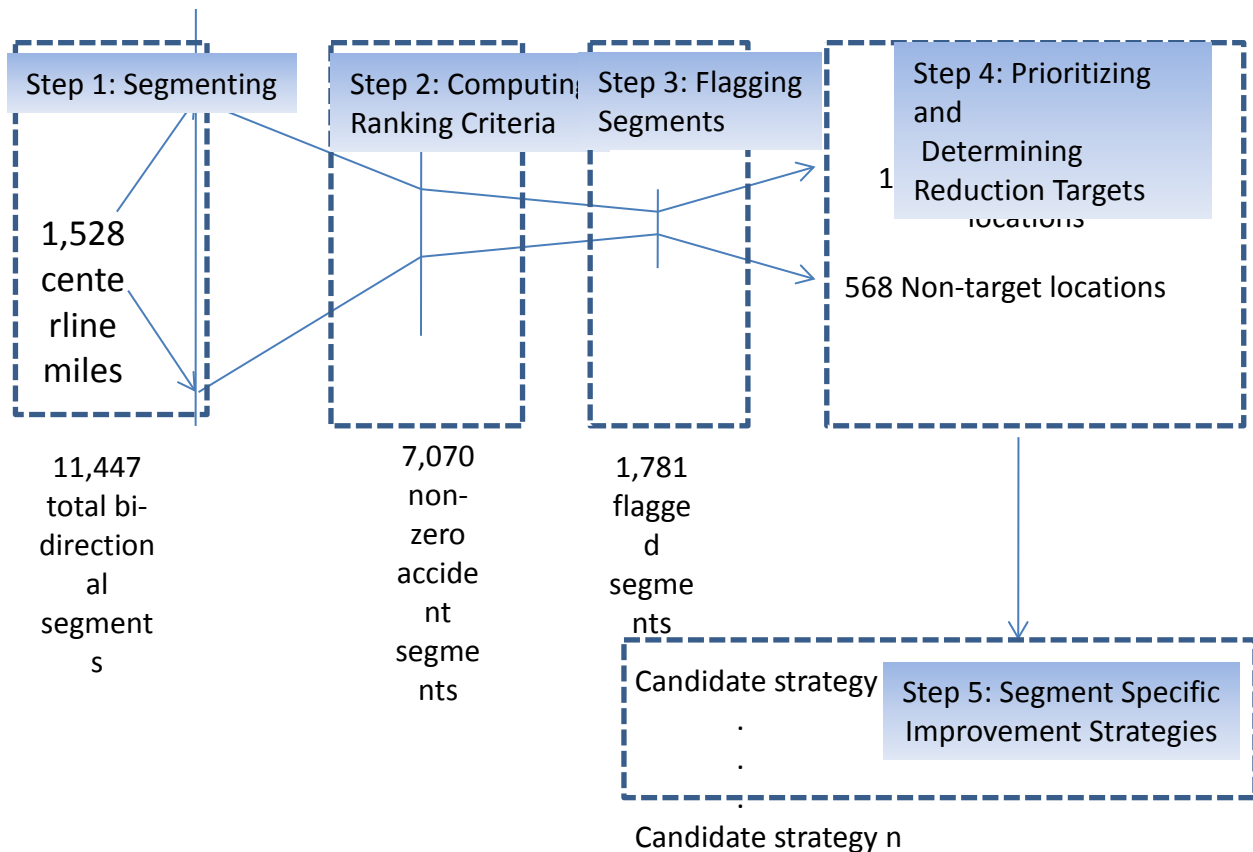
Figure 2. Process Flowchart.

In addition, a total of 161 locations were rated priority two, with an overall length of 103.8 miles and a mean length of 0.64 miles. This targeted length represents 6.8 percent of bidirectional centerline miles of the interstate network. All of these locations involved reduction targets primarily oriented at multi-vehicle collisions. In addition, for future tracking purposes, 1,579 locations are recommended. This is a substantial length of the interstate network comprising 90 percent of total bidirectional length.

At this stage, which meets the planned scope of this study, the target priority list comprises a total of 202 locations for a total length of 154.5 miles. It is recommended that this list be evaluated in detail for scoping improvements, associated costs, and benefits prior to evaluating locations in the "tracking list." The next step in ensuring implementation and successful deployment of this procedure is to carefully

evaluate cost improvement strategies and estimate associated benefits. Several procedures are available here – to identify improvement scenarios using at least one low-cost and one high-cost alternative, and then estimating the benefits for each alternative. Estimating benefits can be done using accident reduction factors, if available. In the absence of accident reduction factors, statistical models showing differences in geometric effects for Washington State interstates may be used. Once costs and benefits are computed, one can systematically proceed to evaluate various measures of cost efficiency and effectiveness using life-cycle and annualized benefits and costs.

References

1. Albin, R.B., Bullard, D.L., Jr., and Menges, W.L. (2001). "Washington State Cable Median Barrier," *Transportation Research Record,* 1743:71-79.
2. Chayanan, S., Shankar, V.N., Sittikariya, S., Ulfarsson, G.F., Shyu, M.B., and Juvva, N. (2004). *Median Crossover Crash Analysis and the Effectiveness of Median Barriers*, Report No. WA-RD 580.1, Washington State Transportation Center.
3. Glad, R.W., Albin, R.B., McIntosh, D.M., and Olson, D.K. (2002). *Median Treatment Study of Washington State Highways*, Washington State Department of Transportation Report No. WA-RD 516.1, 24 pp.
4. Milton J., Shankar, V.N., and Mannering F.L. (2008). "Highway accident severities and the mixed logit model: An exploratory empirical analysis," *Accident Analysis and Prevention,* 40(1):260-266.
5. Milton, J., and Mannering, F. (1998). "The relationship among highway geometrics, traffic-related elements and motor-vehicle accident frequencies," *Transportation*, 25(4):395-413.
6. Shankar, V.N., Sittikariya, S., and Shyu, M.B. (2006). "Some Insights on Roadway Infrastructure Design for Safe Elderly Travel," *International Association of Traffic Safety Sciences*, 30(1):21-26.
7. Shankar V.N., Ulfarsson, G.F., Pendyala, R.M., and Nebergall, M.B. (2003). "On the Modeling of Crashes Involving Pedestrians and Motorized Traffic," *Safety Science*, 41(7):627-640.
8. Shankar, V.N., Albin, R.B., Milton, J.C., and Mannering, F.L. (1998). "Evaluating Median Cross-Over Likelihoods with Clustered Accident Counts: An Empirical Inquiry Using the Random Effects Negative Binomial Model." *Transportation Research Record*, 1635:44-48.
9. Shankar V.N., Milton, J.C., and Mannering, F.L. (1997). "Modeling Accident Frequencies as Zero-Altered Probability Processes: An Empirical Inquiry," *Accident Analysis and Prevention*, 29(6):829-837.
10. Shankar, V.N., Mannering, F.L., and Barfield, W. (1996). "Statistical Analysis of Rural Freeway Accident Severity." *Accident Analysis and Prevention,* 28(3):391-401.
11. Shankar, V.N., Mannering, F.L., and Barfield, W. (1995). "Effect of Roadway Geometrics and Environmental Conditions on Rural Accident Frequencies." *Accident Analysis and Prevention*, 27(3):371-389.