Research Report KTC-04-31/FR121-02-2I

EVALUATION OF US 119 PINE MOUNTAIN SAFETY IMPROVEMENTS: IHSDM ANALYSIS OF POST CONSTRUCTION

by

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in cooperation with

Kentucky Transportation Cabinet
Commonwealth of Kentucky

December 2004

EXECUTIVE SUMMARY

The spot improvements on US 119 in Letcher County between Whitesburg and Partridge were an attempt to improve safety throughout the corridor. To achieve this goal, the roadway alignment and cross section were changed at various locations. In addition, problems related to truck traffic were considered in redefining the roadway geometrics. The total length of the spot improvement locations was approximately 6.9 miles.

The Kentucky Transportation Center at the University of Kentucky was requested to evaluate safety related to the implemented changes to alignment and roadway cross section and post-construction conditions. This report is a safety analysis of the post-construction conditions based on the changes made to the alignment and roadway cross section using a newly released software by the Federal Highway Administration. The software is the Interactive Highway Safety Design Model (IHSDM) and evaluates the geometry of the roadway and crash prediction models to compute the expected safety performance of the roadway.

The pre-construction crash rate for the section of US 119 with these spot improvements, between milepoints 10.065 and 17.161, was 430 crashes per 100 million vehicle-miles (C/100MVM). The average expected crash rate calculated by IHSDM for the post-construction conditions is 302 C/100MVM. The Locations that have an expected crash rate exceeding the statewide average crash rate for rural, two-lane highways, which is 250 C/100MVM, are 1090-1129 (505 C/100MVM), 1460-1620 (358 C/100MVM), and 1670-1696 (253 C/100MVM). The post-construction expected fatal and injury crash rate is 97 C/100MVM, which is higher than the statewide average of 86 C/100MVM and pre-construction injury crash rate of 91 C/100MVM for this section.

The software was used to evaluate the impact of various geometric changes on the safety performance of the roadway. The newly constructed conditions were considered as existing and changes to various geometric features were implemented to determine their effect on crashes. Increasing the lane width in extreme horizontal curves reduces the expected crash rates by allowing vehicles to track in designated lanes. The total roadway width (travel lanes and shoulder) is directly related to expected crashes and has the largest impact on the safety for a rural road of this type. Travel lanes on horizontal curves with small radius and large degree of curvature should be wider than typical to provide the driver more room for error. When considering tradeoffs in the total roadway cross section width, it is more important to provide wider lanes than wider shoulders in the equivalent total width.

Increasing the radius of horizontal curves does not necessarily increase safety. This should be evaluated in relation to the approaching tangents, since short tangents will have a negative effect on overall safety.

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1. INTRODUCTION

The purpose of this study is to evaluate the spot improvements of US 119 from Partridge to Whitesburg in southeastern Kentucky using the newly released software by the Federal Highway Administration (FHWA), Interactive Highway Safety Design Model (IHSDM). The safety improvements on US 119 cover 6.9 miles at a projected cost of approximately $36 million. US 119 is a rural principal arterial with a "AAA" weight classification; which allows traffic loads up to 80,000 pounds. US 119 is on the National Highway System, State Primary System, Appalachian Development Highway System, and the Defense Highway Network (1). This report presents the results of phase two of the "Evaluation of US 119 Pine Mountain Safety Improvements" report requested by the Kentucky Transportation Cabinet.

2. LITERATURE REVIEW

The U.S. Department of Transportation Federal Highway Administration began the conceptual design of a software, Interactive Highway Safety Design Model, in 1994 to enable planners and engineers to provide "quality" design for rural, two-lane highways (2). The slogan for IHSDM is "Safer Roads Through Better Design" (3). Quality design is defined as the combination of the accepted, safe, and efficient designs of a roadway. The objective of the software is to allow engineers and designers to consider safety characteristics of a roadway design (2). The software provides tools to analyze operational and safety effects on geometrics of rural, two-lane roadways by comparing designs separately. IHSDM was originally intended for state agencies to evaluate safety of existing and future roadways. For convenience, IHSDM is designed to be compatible with computer-aided design (CAD) software. Currently, IHSDM can be implemented throughout the planning and design processes for both construction and reconstruction of roadways (3).

The roadway type most often encountered in the U.S. is the two-lane highway. FHWA statistics indicate that two-lane, two-way roads represent 82.4 percent of the U.S. network. Similarly, in Kentucky two-lane, two-way roads represent 81.0 percent of the Kentucky network (4). IHSDM was initially designed for this class of roadway because of the constant improvements to geometrics of such roads (5). Development for IHSDM to evaluate multi-lane highways is currently under way to also provide designers and planners with further options for evaluating alternative designs (3). The IHSDM structure includes five separate but linked modules to allow the designer to describe roadway geometrics, existing traffic, and crash history of the roadway under review. The current module that can evaluate the existing conditions and predict future performance are the Policy Module, Design Consistency Module, Intersection Review Module, Traffic Analysis Module, and Crash Prediction/Accident Analysis Module (3,5). A sixth module, Driver/Vehicle Module, is currently being developed (3).

The Policy Review Module checks the provided geometric data with a specified policy. The user can choose for comparison the American Association of State Highway and Transportation Officials (AASHTO) Green Book, state policies, or other policies. This module will identify segments that vary from the policy guidelines by checking relevant policies dealing with cross section, horizontal alignment, vertical alignment, and sight distances. The cross section category under the Policy Review Module checks the "through-traveled way width and cross slope, auxiliary lane width and cross slope, shoulder width and cross slope, cross slope rollover on curves, clear zone and roadside slope, normal ditch design, and bridge width". The module is utilized to clarify whether the policy goal is satisfied and the section conforms to these guidelines. The radius of curvature, length of horizontal curve, compound curve ratio, and superelevation rate and transition design components of the horizontal alignment are also checked. Another geometric characteristic of the roadway checked is the vertical alignment where the tangent grade and vertical curve length components are compared to policy values (3).

The Traffic Analysis Module estimates operating conditions based on data entered from existing conditions, such as 85th percentile speed, percent time spent following another vehicle, and quality of service. The module also predicts operating conditions based on a given traffic population growth (5). The module uses the TWOPAS traffic simulation model to evaluate the microscopic characteristics of traffic simulation, such as percentage of time spent following other vehicles and average operating speed (6). This module can be used in the preliminary design process for comparing the traffic operational characteristics of different geometric changes (3).

Crash data and other attributes are used by the Crash Prediction/Accident Analysis Module to estimate the number and severity of crashes, calculate safety benefit-versus-cost, and evaluate geometric and intersection designs (5). Crash frequencies are predicted based on lane width, shoulder width and type, horizontal curve length and radius, presence of spiral transition, superelevation, grade, driveway density, passing lanes and short four-lane sections, two-way left-turn lanes, and roadside hazard data. In addition, the algorithm utilizes crash modification factors and statistical base models to predict crash frequencies (6). Furthermore, intersection variables and types are assessed in this module. Analysis of different types of intersections is also central because on rural two-lane highways, about one third of all crashes occur at intersections (3). There are only three types of intersections that can be examined: four legged intersection with signal control, four legged with stop control on the minor approach, and three legged with stop control on the minor approach (3). The cost-benefit feature of the model was not available in the current version used in the evaluation.

The Intersection Review Module is comprised of a policy and diagnostic review check. The module checks the corner radius, turn lane design, intersection angle, and intersection sight distance triangles according to policy. The horizontal geometric intersection design issues evaluated by the module are intersections on horizontal curves, curves on intersection legs, and approach alignments. In addition to horizontal geometrics, the vertical alignment components, intersection configuration, and intersection sight distances are evaluated (3).

The horizontal alignment is analyzed by the Design Consistency Module. Crashes on horizontal curves on rural, two-lane highways are mainly attributed to speed inconsistencies. The two consistency problems assessed by the module are the differences between design speed and 85^{th} percentile speed and changes in 85^{th} percentile speed between consecutive roadway sections (3). The 85^{th} percentile speed is estimated using a speed profile model that was calibrated using speed data collected on horizontal curves and approaching tangents from previous research. The speed profile is then used to examine and identify potential consistency problems (5). The module output provides graphs of the speed profile and identifies sections of roadway that do not comply with design consistency as designated by policy (5).

The Driver/Vehicle Module will consist of two models, Driver Performance and Vehicle Dynamic Model, that will be linked to better evaluate driver conditions and characteristics that could cause a possible accidental action under given circumstances (5,7). The Driver/Vehicle Module will evaluate if conditions exist that would cause, or contribute to, the driver losing control of the vehicle and eventually result in a crash. In addition, the driver operations will be evaluated and modified to evaluate the roadway design with different types of drivers. The module will eventually allow for examining the impact of different types of vehicle characteristics and specifically heavy vehicles. This module is not available yet in the current IHSDM software (6).

As previously mentioned, IHSDM is designed to be eventually compatible with computer-aided drafting software. Commercial software design components will be compatible with IHSDM. Most of the geometric roadway design data will be available for automatic importing into and exporting once the FHWA and commercial CAD developers develop a common software language (3).

The design of the horizontal and vertical alignments of a roadway is crucial for safe travel on highways. Design speed determines stopping sight distances which dictate length of vertical curves. There are safety concerns on vertical curves (8). Rear end, animal, angle, and pedestrian crashes are affected by vertical alignment due to potential sight distance problems (13). The crash rate on the downgrade of a vertical curve is higher than the upgrade by 63-percent (8). The frequency of crashes is higher on downgrades than upgrades for crest and sag curves. Injury and fatality rates and crash frequency involving trucks are higher on vertical curves than level grade (8).

Key elements of the horizontal alignment affect safety and crash occurrence. Crash rates are much higher on horizontal curves than on tangents. Traffic volume and mix, cross section elements, roadside hazards, stopping sight distance, vertical alignment, and pavement friction of horizontal curves contribute to the safety on highways. Objects by the side of a curve, intersections within a curve, and tangent distance between horizontal curves can affect safety. Crash rates on horizontal curves can be reduced by changing the degree of curvature and length. Widening of lanes and shoulders, inserting spiral transitions, as well as superelevation and roadside improvements can reduce crash frequencies on horizontal curves (8). The average run-off-road crash rate involving a single vehicle is four times higher on a horizontal curve than on a tangent (9). Shoulder and lane widening have the largest impact in reducing ran off road and opposite direction crashes, with lane widening having the larger effect in reducing such crash types. Lane and shoulder widening are not directly related to any other type of crash other than ran-off-road and opposite direction crashes. The type of shoulder has a direct effect on crash rates, and stabilized shoulders have a lower crash rate than non-stabilized shoulders (10).

In review, IHSDM is capable of evaluating the driver performance and design attributes of a two lane rural highway for analysis. The horizontal and vertical alignment and cross section dimensions are contributing to crashes. Lane widths and shoulder widths are the most significant contributors to ran-off-road and opposite direction crashes.

3. PRE-CONSTURCTION SAFETY CONDITIONS

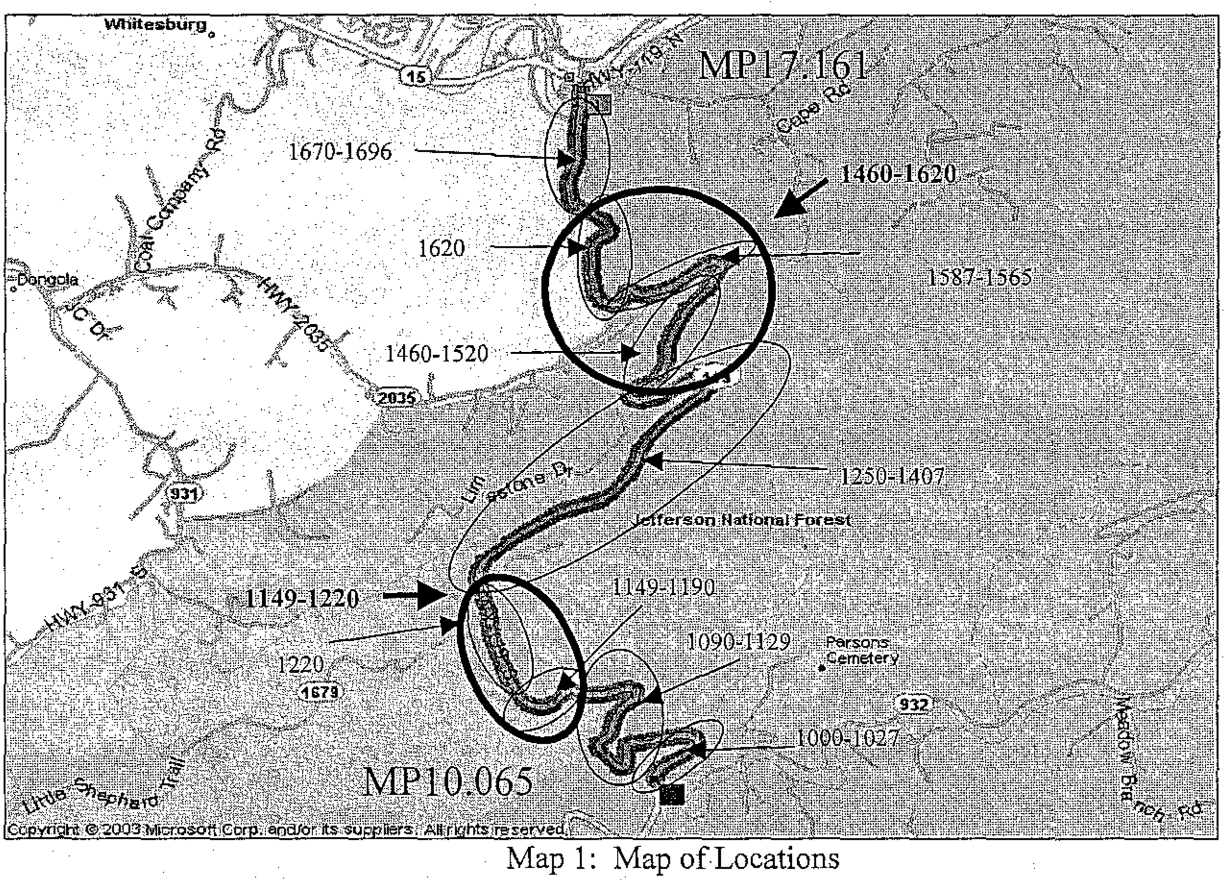
The crash history on US 119, between mile points 10.065 to 17.161, across Pine Mountain indicated 118 crashes between 1996 and 2000 (7). The crash rate for this section is 430 C/100MVM, which is significantly higher than the statewide average for rural, two-lane highways (250 C/100MVM) (7,11). The critical rate[1] is 328 C/100MVM, resulting in a 1.31 critical rate factor (7). For the sections with a critical rate factor greater than 1.0, then the crashes considered may not be occurring at random (1). The traffic on US 119 has a considerable amount of truck traffic, roughly 8 percent. The location of the roadway is in southeastern Kentucky and used by coal truck traffic and single trailer trucks, 0.6 percent and 2.7 percent respectively. Even though US 119 has a significant amount of truck traffic, it is not a designated Coal Haul Route or part of the National Truck Network (1). The pre-construction geometric cross section and horizontal and vertical alignments on the study section prohibit trucks from remaining within their designated lane. Sharp curves and narrow lane widths also contribute to encroachment into the opposite flow of traffic by multi-axle trucks and possibly contribute to crash occurrence. The statewide average percentage of crashes involving trucks is 7 percent (6), while in the study area 61 percent of accidents involved trucks with the most common crash type being sideswipe (1). The sharp curves and lane width of the roadway are directly contributing to this particular crash type.

[1] The critical rate is the upper limit established for all roads over which road sections are considered less safe. The critical rate factor is the ratio of the crash rate over the critical rate.

4. POST CONSTRUCTION CONDITIONS

4.1. IHSDM Software Analysis

IHSDM software was utilized to evaluate the reconstructed roadway. The entire roadway was separated into sections to address the specific design challenges in a more time sensitive manner. The spot improvement locations were not all continuously stationed, and therefore the locations were evaluated separately. Locations 1460-1520 and 1565-1620 and 1220 and 1149-1190 were combined because they were found to be in sequential order. Such combinations increase the segment length in order to provide a more accurate analysis. The following map describes the location of the project and illustrates which roadway project locations were combined.



Map 1: Map of Locations

The roadway spot improvements along the study area were difficult to analyze with IHSDM because previous geometric data were not available in any form. In addition, the consultants who completed the design stated that on-site changes were made that were not duplicated in the drawings provided. The previous geometric data of the roadway would have been helpful in considering and evaluating different possible designs through IHSDM and comparing them with the pre-construction conditions. However, the lack of pre-construction data does not hinder illustrating how IHSDM can evaluate roadway geometric changes.

In order to simplify data entry and lack of detailed information some attributes were considered as constant throughout the entire 6.9 miles of construction. The following assumptions were made:

- The 2004 ADT for the entire project was 2,900 vehicles per day with 10 percent of the traffic comprised of heavy trucks.
- A maximum design speed of 40 miles per hour was assumed, since the roadway was never designed to a specific design speed, but speed varied by surrounding environmental factors.
- An operating speed of 40 miles per hour was assumed as the desired speed of traffic entering and exiting the project.
- The design vehicle evaluated was a WB-50 intermediate semi-trailer. The software does not allow for the weight of the design vehicle in predicting crash rates, and therefore the impact of high coal truck traffic can not be evaluated.
- The design vehicle was only used in the Policy Review Module.

- The vehicle used in the Design Consistency Module analysis was chosen to have a maximum acceleration of 11.17 feet per second per second and maximum speed of 112.8 feet per second which was the lowest vehicle speed.
- The type of project was reconstruction
- The maximum superelevation was chosen to be 10 percent.
- The software also calls for a roadside hazardous rating number (a number between 1 and 7, where 1 is open roadside with adjacent clear zones and is the most desired roadside). This rating has been defined in IHSDM and based on the suggested roadway description, a rating of 5 was given to the given area (5). IHSDM defines a roadside hazard rating of five to include a clear zone between 5 to 10 feet from pavement edge, a side slope approximately 1:3, and guardrail 0 to 5 feet and rigid obstacles or embankments within 6.5 to 10 feet from pavement edge. If a vehicle was to leave the pavement edge, it would be virtually not able to recover and reenter the roadway. Appendix A is the description of the ratings defined by the software.

IHSDM requires all of the geometric attributes to be entered for full evaluation. The vertical and horizontal alignment, superelevation, lane widths, and shoulder widths by station provided were entered into the software. In addition to these data, past crash data can be used in the formulas to calculate expected crash rates and frequencies. Because the construction of the roadway was not completed early enough to collect crash data, this attribute was not utilized.

4.1.1. Expected Crash Frequencies and Rates

For a sample as to what the ISHDM Crash Prediction/Accident Analysis Module computes for a segment of roadway, a printout is provided in Appendix B for US 119 between mile points 10.003 (Sta. 997+00) and 10.647 (Sta. 1031+00) over a four year analysis period (2005 through 2008). The length of the segment is approximately 0.6439 miles. The Crash Prediction/Accident Module analysis reports the proposed highway, horizontal curve data, and traffic volumes in the analysis period. In addition, the report includes the expected crash frequencies and rates and expected crash type distribution summaries. In more detail, the expected crash frequencies and rates change by roadway segment and by horizontal design element. A set of graphs are provided by the software to visually analyze the roadway. Each of these tables and figures for this location is provided in Appendix B. The graphs illustrate crash rates by segments and horizontal design element by station. The dashed green line in the crash rate by segment graph is the moving average of the crash rate per mile per year. In addition, roadway elevation and radii are provided.

Based on these data, the crash rate for the section is 192 C/100MVM, which is less than the state average. The graphs indicate the locations with potential problems are at stations 998+64.03 to 1000+29.43 and 1025+69.64 to 1027+50.0 where the sharper curves occur.

The expected crash frequencies and rates summaries for the entire study are compiled in Table 1 and shown in Figure 1 showing the total number of crashes and fatal and injury crashes expected for the analysis period (2005 through 2008). Additionally, the crash rate and fatal and injury crash rate per million vehicle-miles (C/MVM) are shown.

	LOCATION (STATIONS)					
	1000-1027 (997+00-1031+00)	1090-1129 (0+78.41-48+02.76)	1149-1190-1220 (1179+12.9-1225+15)	1250-1407 (1235+00-1344+61.86)	1460-1520-1565-1620 (1490+00-1596+77.45)	1670-1696 (1669+00-1690+06.02)
Length (miles)	0.8439	0.8948	0.8716	2.0761	2.0222	0.3989
Total Crashes	5.6	20.4	8.4	22.5	32.7	4.6
Fatal and Injury Crashes	1.8	6.6	2.7	7.2	10.5	1.5
Property-damage-only Crashes	3.8	13.9	5.7	15.3	22.2	3.1
Average Future Road ADT (vehicles/day)	3094	3094	3094	3094	3094	3094
Crash Rate per miles per year	2.17	5.7	2.42	2.7	4.05	2.86
Fatal and Injury Crash Rate per miles per year	0.7	1.83	0.78	0.87	1.3	0.92
Property-damage-only Crash Rate per miles per year	1.47	3.87	1.64	1.84	2.75	1.94
Total travel (million vehicle-miles)	2.91	4.04	3.94	9.38	9.13	1.8
Crash Rate per million vehicle-miles	1.92	5.05	2.14	2.39	3.58	2.53
Fatal and Injury Crash Rate per million vehicle-miles	0.62	1.62	0.69	0.77	1.15	0.81

Table 1: Expected Crash Frequencies Rates (2005-2008)

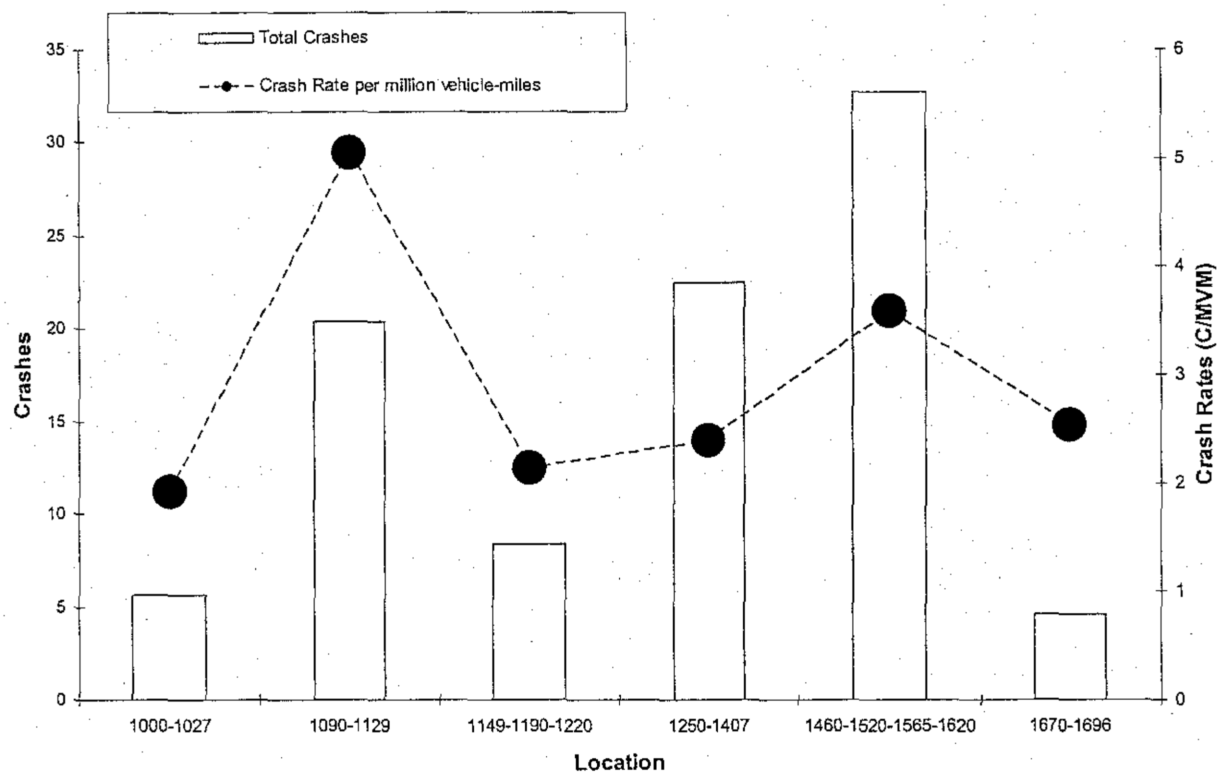


Figure 1: Expected Crash Frequencies and Rates by Location (2005-2008)

The crash rate per 100 million vehicle-miles ranges from 192 to 505 over the entire length of the section which is mainly attributed to the changing nature of various geometric features along the roadway. IHSDM predicts three locations of the reconstructed roadway to have a higher crash rate than the present statewide average. The average expected crash rate for the entire reconstructed roadway is 302 C/100MVM, which is greater than the statewide average crash rate for a two lane rural road (250 C/100MVM). Based on the data in Figure 1, only sections 1090-1129 and 1460-1620 exceed the statewide average. The software also predicts 94.2 crashes throughout the study area for the four year period. Between 1995 and 1999, there were 91 crashes between mile points 10.065 and 17.161 on US 119 or 22.8 crashes per year. The software expects 23.55 crashes per year over the study area between 2005 and 2008 which is slightly higher than the previous crash history. The statewide average injury crash rate per 100 million vehicle-miles is 86. The injury crash rate between mile points 10.065 and 17.161 was 91crashes/100MVM between 1996 and 2000 (7). The expected fatal and injury crash rate is 130 crashes/100MVM for the existing conditions of the roadway. The expected average injury and fatal crash rate computed per 100 million vehicle-miles for the studied section over the 4 year analysis period is 97.1 C/100MVM, which is higher than the state average. Based on the predicted figures, it could be stated that the new roadway will probably demonstrate a similar, if not slightly higher, crash history as the preconstruction facility, both for all crashes and severe crashes.

4.1.2. Expected Crash Type Distribution

The distribution of crash types is also summarized in a table for the entire study area by location (Table 2). Collision with animal (30.9 percent of total) and run-off-road (28.1 percent of total) crashes make up 59.0 percent of all expected crashes. The very small shoulders, sharp changes in horizontal alignment, steep grades, roadway cross section, and high roadside hazard rating are the most likely contributing factors of the high single-vehicle accidents. Multiple-vehicle crashes are expected to be 33.6 percent of the future crashes. The largest type of multiple-vehicle crash is the rear-end collision.

	LOCATION (STATIONS)					
Crash Type	1000-1027 (997+00-1031+00)	1090-1129 (0+78.41-48+02.76)	1149-1190-1220 (1179+12.9-1225+15)	1250-1407 (1235+00-1344+61.86)	1460-1520-1565-1620 (1490+00-1596+77.45)	1670-1696 (1669+00-1690+06.02)
Length (miles)	0.6439	0.8948	0.8716	2.0761	2.0222	0.3989
Single-vehicle accidents	Number (percent)					
Collision with animal	1.7 (30.9%)	6.3 (30.9%)	2.6 (30.9%)	6.9 (30.9%)	10.1 (30.9%)	1.4 (30.9%)
Collision with bicycle	0.0 (0.3%)	0.1 (0.3%)	0.0 (0.3%)	0.1 (0.3%)	0.1 (0.3%)	0.0 (0.3%)
Collision with parked vehicle	0.0 (0.7%)	0.1 (0.7%)	0.1 (0.7%)	0.2 (0.7%)	0.2 (0.7%)	0.0 (0.7%)
Collision with pedestrian	0.0 (0.5%)	0.1 (0.5%)	0.0 (0.5%)	0.1 (0.5%)	0.2 (0.5%)	0.0 (0.5%)
Overturned	0.1 (2.3%)	0.5 (2.3%)	0.2 (2.3%)	0.5 (2.3%)	0.8 (2.3%)	0.1 (2.3%)
Ran off road	1.6 (28.1%)	5.7 (28.1%)	2.4 (28.1%)	6.3 (28.1%)	9.2 (28.1%)	1.3 (28.1%)
Other single-vehicle accident	0.2 (3.6%)	0.7 (3.6%)	0.3 (3.6%)	0.8 (3.6%)	1.2 (3.6%)	0.2 (3.6%)
Total single-vehicle accidents	3.7 (66.4%)	13.6 (66.4%)	5.6 (66.4%)	14.9 (66.4%)	21.7 (66.4%)	3.0 (66.4%)
Multiple-vehicle accidents						
Angle collision	0.2 (3.9%)	0.8 (3.9%)	0.3 (3.9%)	0.9 (3.9%)	1.3 (3.9%)	0.2 (3.9%)
Head-on collision	0.1 (1.9%)	0.4 (1.9%)	0.2 (1.9%)	0.4 (1.9%)	0.6 (1.9%)	0.1 (1.9%)
Left-turn collision	0.2 (4.2%)	0.9 (4.2%)	0.4 (4.2%)	0.9 (4.2%)	1.4 (4.2%)	0.2 (4.2%)
Right-turn collision	0.0 (0.6%)	0.1 (0.6%)	0.1 (0.6%)	0.1 (0.6%)	0.2 (0.6%)	0.0 (0.6%)
Rear-end collision	0.8 (13.9%)	2.8 (13.9%)	1.2 (13.9%)	3.1 (13.9%)	4.6 (13.9%)	0.6 (13.9%)
Sideswipe opposite-direction	0.1 (2.4%)	0.5 (2.4%)	0.2 (2.4%)	0.5 (2.4%)	0.8 (2.4%)	0.1 (2.4%)
Sideswipe same-direction	0.1 (2.6%)	0.5 (2.6%)	0.2 (2.6%)	0.6 (2.6%)	0.9 (2.6%)	0.1 (2.6%)
Other multiple-vehicle collision	0.2 (4.1%)	0.8 (4.1%)	0.3 (4.1%)	0.9 (4.1%)	1.3 (4.1%)	0.2 (4.1%)
Total multiple-vehicle collisions	1.9 (33.6%)	6.9 (33.6%)	2.8 (33.6%)	7.5 (33.6%)	11.0 (33.6%)	1.5 (33.6%)
Total accidents	5.6 (100.0%)	20.4 (100.0%)	8.4 (100.0%)	22.5 (100.0%)	32.7 (100.0%)	4.6 (100.0%)

Table 2: Expected Crash Type Distribution by Location (2005-2008)

4.2. Changes in Geometry

To demonstrate the effects of changes in geometric dimensions of a roadway with the use of IHSDM, several design elements were altered to examine their impact on the safety performance of the roadway. The entire study area contains several sections that are complicated to redesign without significant understanding of the roadway context and design constraints. Therefore, smaller sections were selected to demonstrate such potential applications.

4.2.1. Cross Section Geometric Change

Locations 1450-1520 and 1565-1620 were chosen to evaluate a change in lane and shoulder width and the removal of a climbing lane. The post-construction lane width for this section varies from 12 to 17 feet throughout this section. The 17-foot lane width is in a very sharp curve and is used mostly as a curve approach to reduce tracking problems for trucks. For most of the selected section the right shoulder width is two feet and left shoulder width is four feet. IHSDM was run with several lane and shoulder width combinations. The changes evaluated include lane and shoulder width combinations with the climbing lane removal of existing lane widths+existing shoulder widths, 12+4, 12+3, 11+4, 12+2, 11+3, 11+1, existing+0, 12+0, 10+4, 10+2, and 10+0. The existing+no shoulder with the climbing lane was analyzed in addition to the existing conditions. Figure 2 illustrates the changes made and displays total crashes and crash rates per million vehicle-miles over the analysis period of 2005 through 2008. The first two bars show the effect of the removal of shoulder while maintaining the climbing lane. The remaining bars represent the effects of the various combinations but with the climbing lane removed.

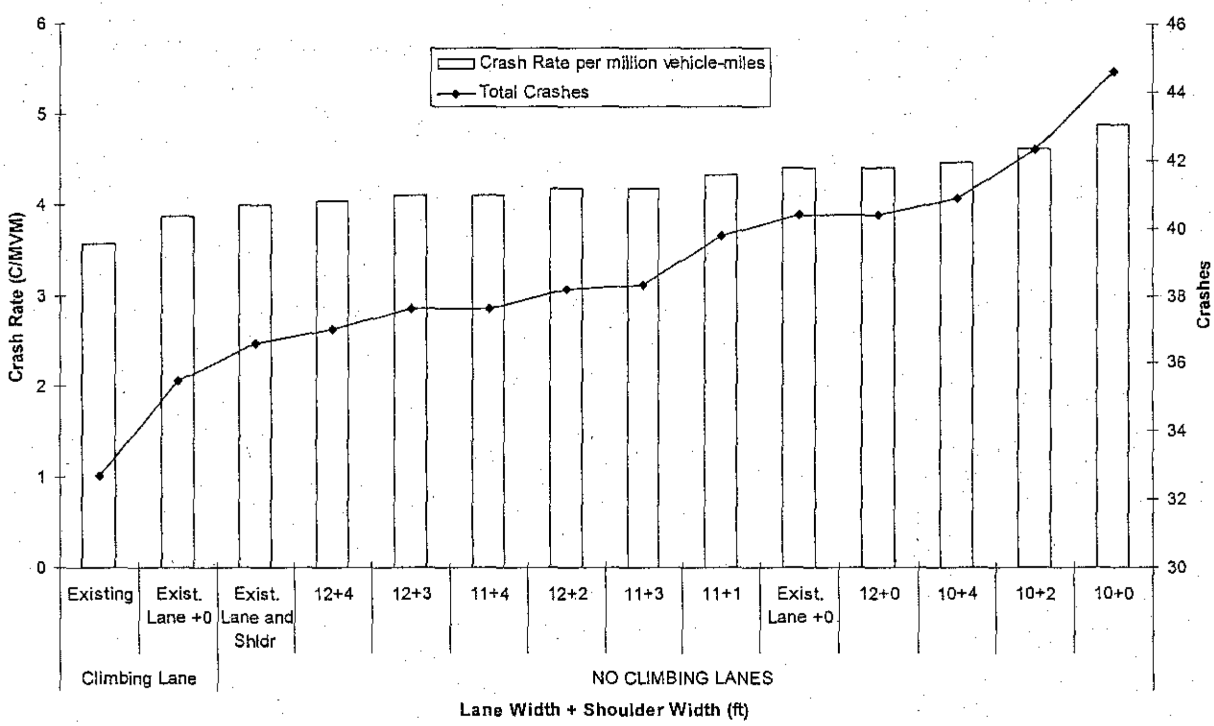


Figure 2: Expected Crashes and Crash Rates: Roadway Geometric Change

The data in Figure 2 indicates that the cross section of the roadway has a large effect on the expected crashes and crash rates. There was a large increase in crash rates between the existing lane and shoulder widths (358 C/100MVM) and analysis of 10-foot lanes and no shoulders (489 C/100MVM). There was also a large increase in the number of crashes from 32.7 in the existing conditions to 44.6 in the 10+0 design.

The closest equivalent cross section combination of the previous condition for this section of roadway is the scenario of 12-foot lanes and 2-foot shoulders without a climbing lane. According to the software results for this analysis, there is an improvement in the crashes/100MVM from 419 (12+2) to 358 C/100MVM(Existing conditions), which is a 14.5 percent improvement. For roadway sections with pre-construction cross section of 10-foot lanes and 2-foot shoulders without a climbing lane, there is 22.6 percent improvement in crashes/100MVM to the existing conditions.

Additional analysis was performed to compare the roadway width with crash rates for this roadway section. Assuming the climbing lane is removed, the following figure illustrates the comparison of the total roadway width with the crashes/MVM and crash rate per miles.

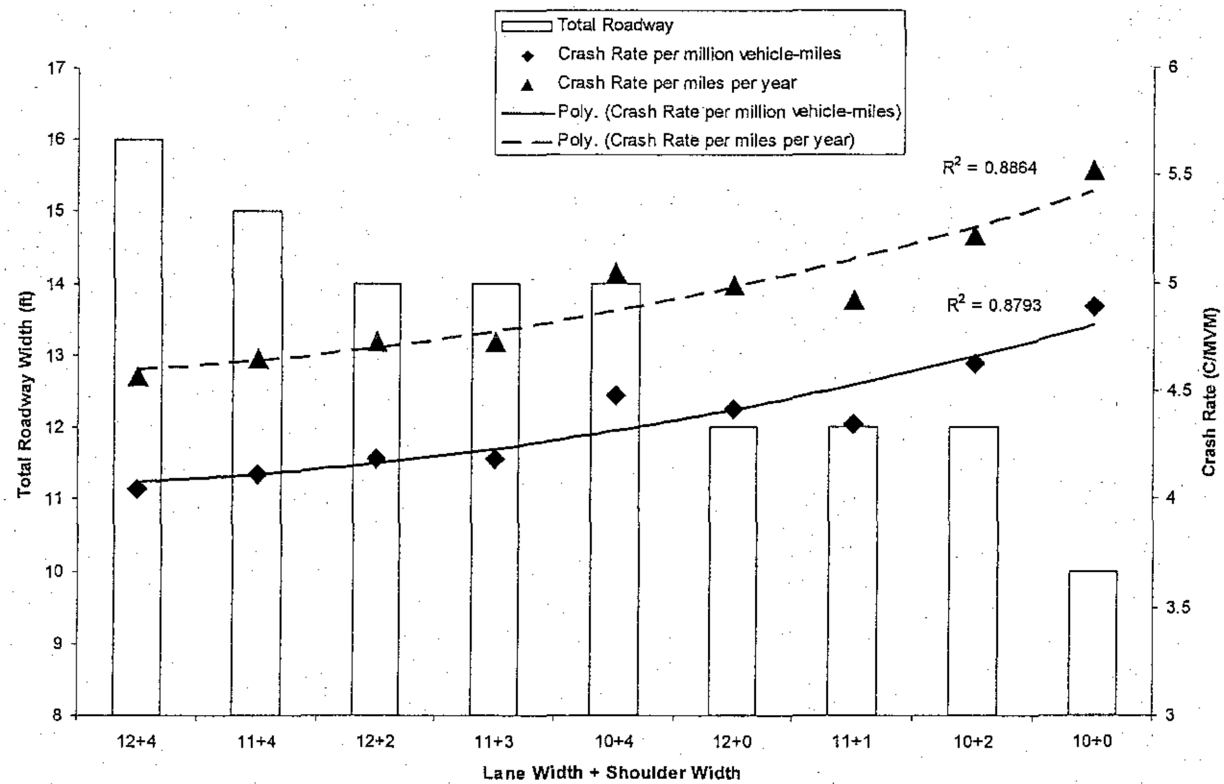


Figure 3: Roadway Width and Crash Rate Comparison

The analysis is grouped by total roadway width. There is not a difference between crash rates or total expected crashes when comparing the roadway with 12-foot lanes and 2-foot shoulders and 11-foot lanes with 3-foot shoulders. Reducing the lane width to 10 feet and increasing the shoulder width to 4 feet resulted in a 7 percent increase in crash rate per million vehicle-miles. There was a 1.5 percent decrease in crash rate per million vehicle-miles from a roadway with 12-foot wide lanes and no shoulders to one with 11-foot wide lanes and 1-foot shoulders. For a roadway with 10-foot lanes and 2-foot shoulders, there was an increase of 6.4 percent in crash rate per million vehicle-miles when compared to the 11-foot lanes and 1-foot shoulders combination. Therefore, these data indicate that 10-foot lanes should be avoided, since they have the potential of increasing crash rates while 11 and 12-foot lanes seem to perform equally well and could be used as needed to accommodate other project requirements.

Additionally, the expected crash rate for the roadway with 10 foot lanes and 4 foot shoulders combination is greater than for the roadway cross section of 12 foot lanes and zero shoulders expected crash rate. Even though the total roadway width is greater for the 10 foot lanes and 4 foot shoulders, it has a higher crash rate than the roadway with 12 foot lanes and zero shoulders, which also supports the finding that the lane width is the more important geometric feature regarding crash potential.

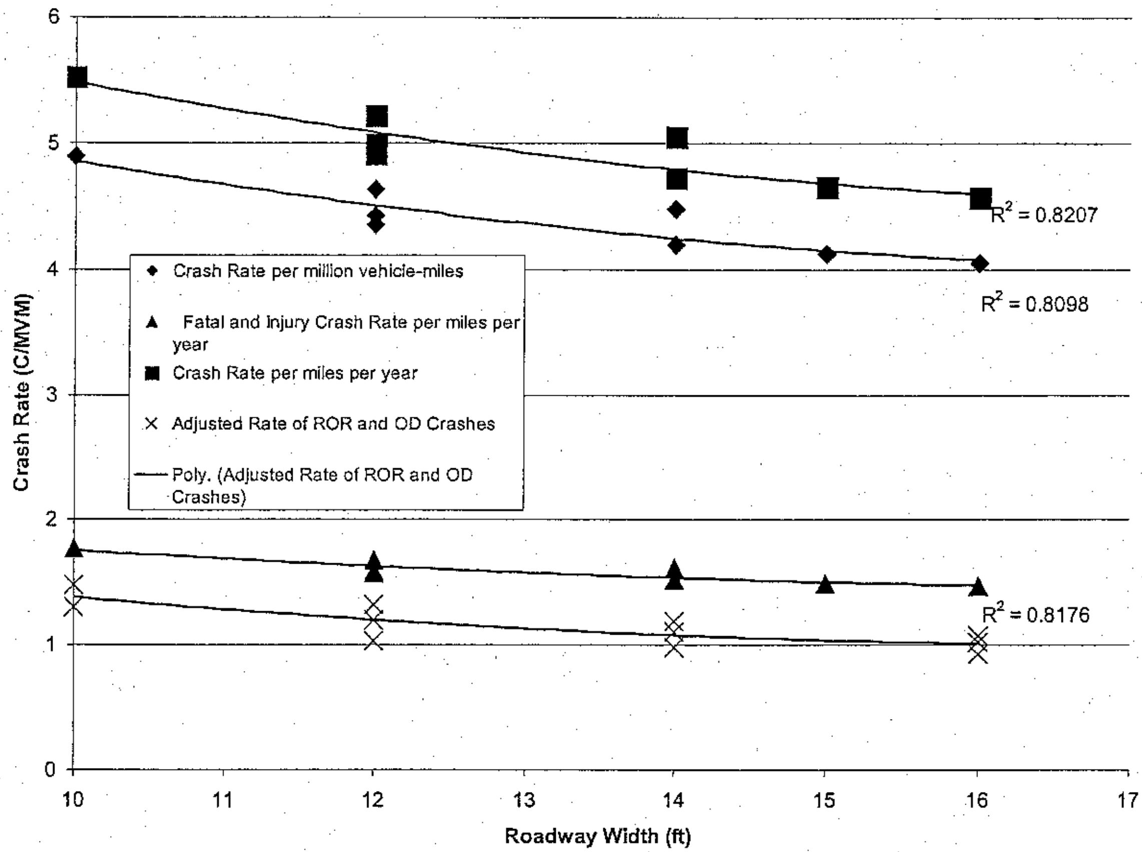


Figure 4: Roadway Width and Crash Rates Regression

Figure 4 shows the relationship of the entire roadway width to the crash rates. There is a strong relationship between roadway width and the three designated crash rates shown in the above figure. The R-squared value for all three crash rate cases is close to 0.85, which shows a well-defined relationship. It has been shown that lane and shoulder width widening is directly related to safer travel on highways, and that widening the width of the travel lane has a larger impact on crash rates than shoulder width widening (10). There is a seven percent increase in crash rate per 100 million vehicle-miles from a roadway with 12 foot lanes and 2 foot shoulders to a roadway with 10 foot lanes and 4 foot shoulders.

The adjusted crash rate for run-off-road and opposite direction data was computed using a model derived by Zeeger and Deacon (10) and provided in Figure 4. The trend of crash rate between the IHSDM crash rates by total road width is very similar to the run-off-road and opposite direction crash rate by roadway width. According to the previous work the two types of crashes were chosen because of their high percentage of occurrence on highways and accessible data.

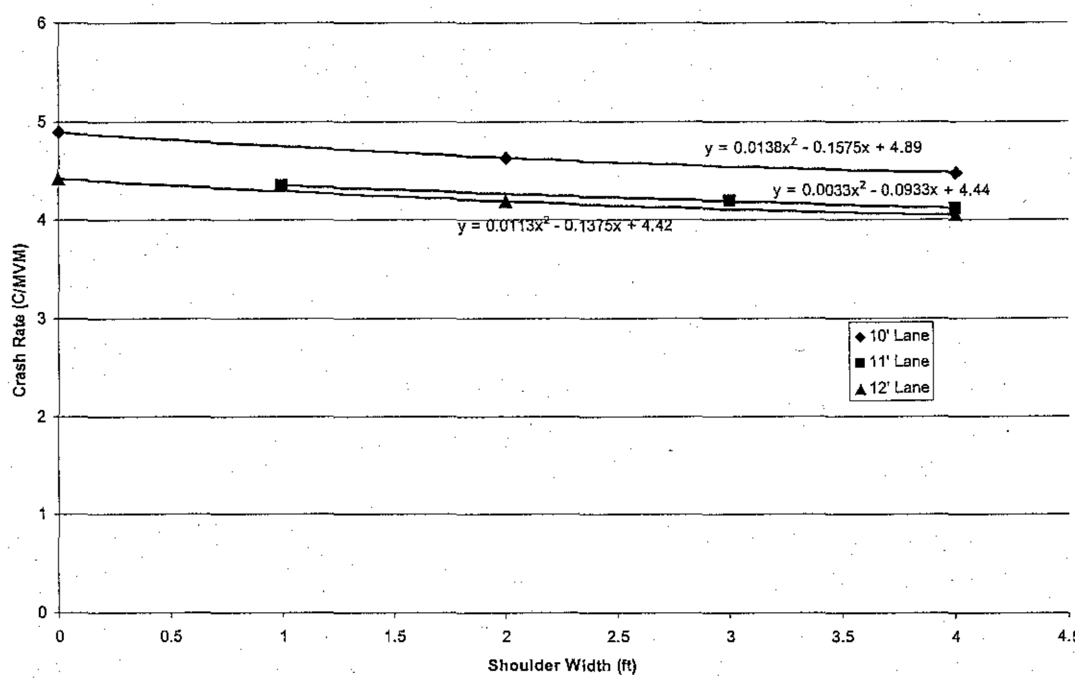


Figure 5: Shoulder Width Comparison Between Lane Widths

Figure 5 depicts the crash rate per million vehicle-miles for shoulder widths by lane width. These data also confirm that there is little gain from the addition of the shoulder and the crash rates are somewhat similar among three lane widths.

4.2.2. *Horizontal Alignment Change*

In addition to cross section geometric dimensions, horizontal and vertical alignments could be changed and evaluated. The first alignment change involved completely removing a series of curves. The curves removed are located in Location 1220 between stations 1216+89.570 and 1223+72.340. Figure 3 shows the results of the analysis before and after the curve removal. The curve removed was very sharp and was adjacent to a house and property; therefore, removal of the curve would result in relocation of the residents. The length of roadway analyzed was 0.43 miles. These data indicate that the curve removal would result in a 66-percent reduction in total crashes and a 67-percent reduction in crash rate per million vehicle-miles over the analysis period.

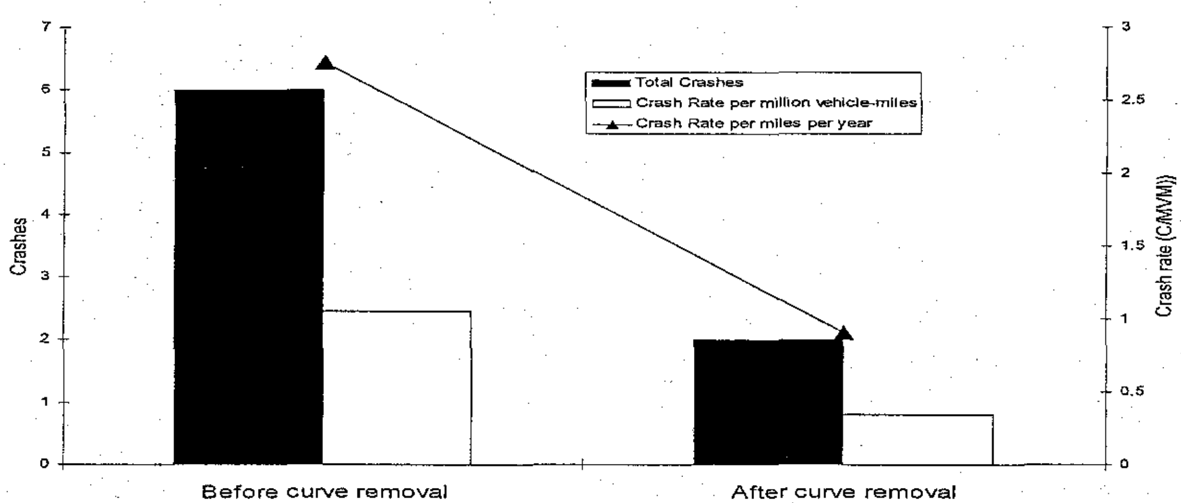


Figure 6: Expected Crashes and Crash Rates: Curve Removal

Removing the set of curves to improve the horizontal alignment and safety is probably an extreme solution for this roadway context. The cost of constructing such an alignment would probably exceed the benefit of reducing the total crashes and crash rates.

The second horizontal alignment adjustment was made in Locations 1460-1520 and 1565-1620. The post construction radius of curvature is 244 feet and is located between stations 1561+47.200 and 1564+39.640. An analysis was completed on increasing the radius to 375 feet and decreasing it to 70 feet. An analysis on a curve with a 70 foot radius was chosen because it is the minimum radius used for the constructed roadway. A radius of 375 feet was chosen because it is higher than the average curve radius in the section. Figure 7 illustrates the results of a four year analysis (2005 through 2008) of the curve only.

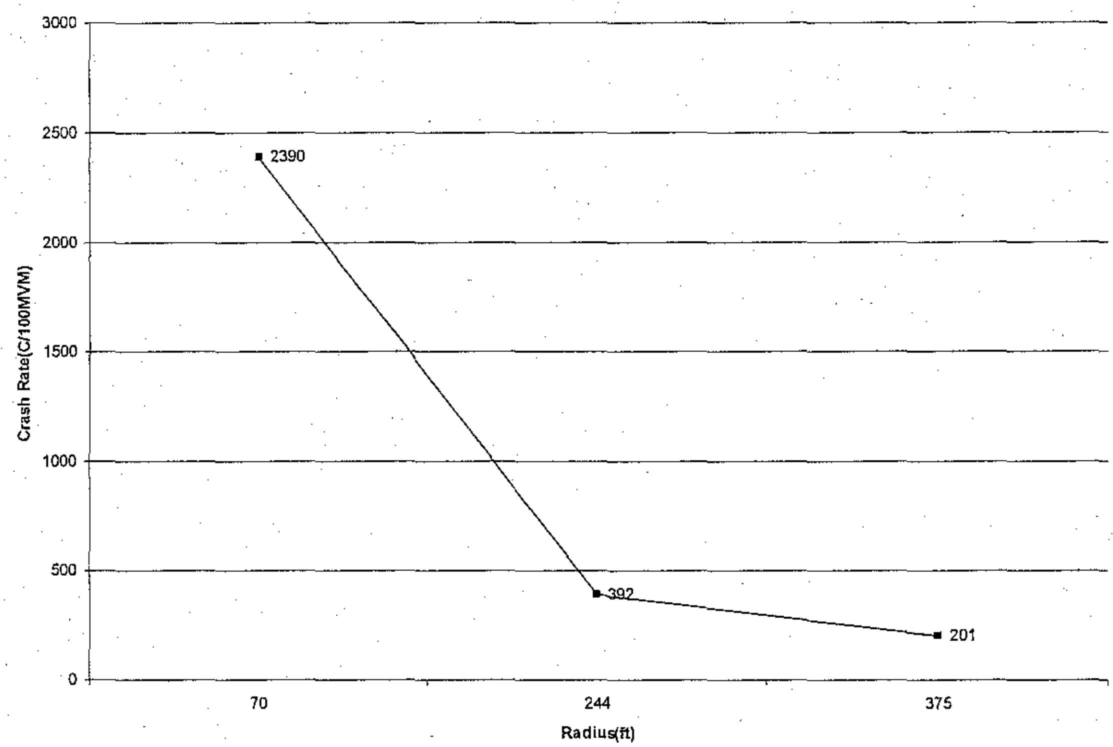


Figure 7: Expected Crash Rates: Radius Change: Curve Only

As shown from Figure 7, the crash rate dropped from 392 to 201 C/100MVM from increasing the radius, which agrees with literature stating such an alignment improvement decreases the total crashes on curves (8). As expected, decreasing the radius to 70 feet resulted in a very large increase in crash rate (510 percent).

To fully evaluate the effect of increasing and decreasing the radius and tangents, an analysis of the same scenarios was conducted including the preceding and following curve and tangent about the changed curve. The results are compiled into Figure 8.

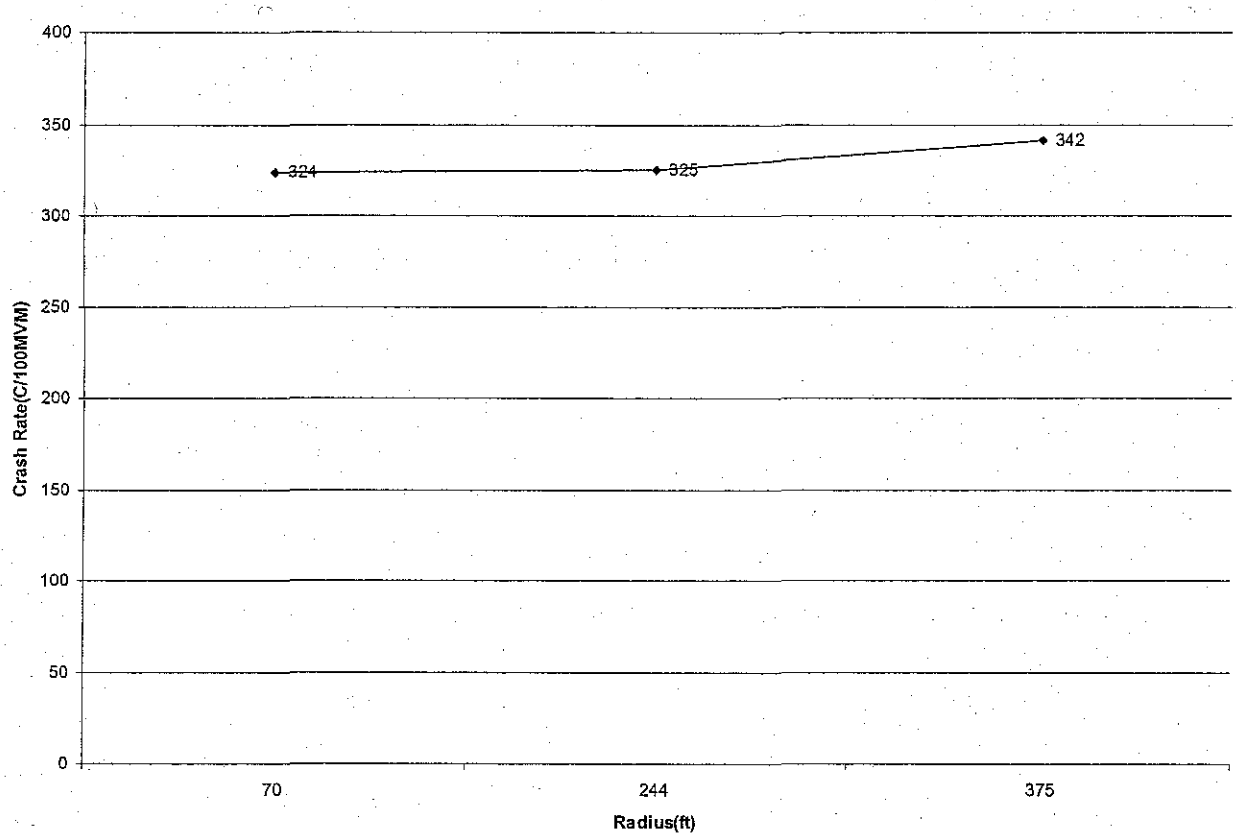


Figure 8: Expected Crash Rates: Radius Change

Increasing the radius from 244 feet to 375 feet resulted in a slightly higher crash rate. In fact, there was a 5 percent increase between the two categories from this change where the radius was increased and the curve was flattened. This analysis considered the tangents and curves before and after the changed curve. The results show that the length of the roadway is the most important factor since sharper curves will result in longer tangents and the overall crash rate remains somewhat similar (324C/100MVM for 70-foot radius as compared to 325 C/100MVM for 244-foot radius). The flatter curve produced a higher rate because of the longer curve that resulted in eliminating any tangent between the sections. Therefore, the proper way for evaluating such changes is to consider the adjacent sections along with the curve.

5. CONCLUSIONS

Analyzing the post construction roadway and changes in geometric cross section and horizontal alignment to the roadway with IHSDM resulted in the following findings.

Geometric and Alignment Analysis

- Opposite sideswipe crashes are not illustrated very well because the design vehicle is not considered into the calculations for the Expected Crash Prediction Module.
- Increasing lane width in extreme horizontal curves reduces expected crash rates by allowing wider lanes for vehicles to track within their designated lanes.
- The total roadway width (lane and shoulder) is directly related to the expected crash rate, although it is also more important to provide wider lanes than wider shoulders for vehicles within the same total width.
- On horizontal curves, increasing the radius does not necessarily increase safety. Horizontal curve flattening should not be implemented if adjacent tangents are reduced to an unsafe distance. It is more beneficial to have longer tangents with reasonable curves.
- The largest impact on safety for a rural road of this type is providing a wide total roadway cross section; travel lanes on horizontal curves with small radius of curvature and large degree should be wider than typical to provide the driver more room of error.
- A truck climbing lane has a positive effect on safety.
- If previous geometric data was available, a comparison of different designs could have been performed to evaluate more precisely the improvements made to the roadway

Existing Conditions Analysis

- Locations that have an expected crash rate per million vehicle-miles higher than the state average are: 1090-1129 (505 C/100MVM), 1460-1520-1565-1620 (358 C/100MVM), and 1670-1696 (253 C/100MVM)
- The average expected crash rate for the roadway study is 302 crashes/100 MVM; as compared to the statewide average of 250 crashes/100MVM.
- The average expected fatal and injury crash rate for the roadway study is 97 crashes/100 MVM: as compared to the statewide average of 86 crashes/100MVM.
- According to the shoulder width comparison between lane widths of Locations 1460-1520-1565-1620, a roadway that has 12 foot lanes and 2 foot shoulders has an equivalent crash rate to a roadway with 11 foot lanes and 3 foot shoulders.
- Lane widths of 11 and 12 foot similar expected crash rates and both have a lower crash rate than 10-foot lanes

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11. Agent, K.R.; Pigman, J.G.; and Barrett, M.L.; "Analysis of Traffic Crash Data in Kentucky (1996-2000)," KTC-01-25/KSP2-01-1F, September 2001.

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Appendix A
Supplemental Literature: Roadside Hazard Rating

Roadside Hazard Ratings used by IHSDM

This page describes the roadside hazard rating values used by IHSDM. The roadside hazard rating value
Prediction Module. This description is adapted from Appendix D of Publication **No. FHWA-RD-99-20**
Expected Safety Performance of Rural Two-Lane Highways .

The roadside hazard rating system is based on the system developed by Zegeer, et al. to characterize the
roadside designs found on two-lane highways. Roadside hazard is ranked on a seven-point categorical sc
(worst). The seven categories of roadside hazard rating are defined as follows:

- **Rating = 1**
  - Wide clear zones greater than or equal to 9 m (30 ft) from the pavement edgeline.
  - Sideslope flatter than 1:4.
  - Recoverable.

  Figure 1, *Typical Highway with Roadside Hazard Rating Equal to 1*
- **Rating = 2**
  - Clear zone between 6 and 7.5 m (20 and 25 ft) from pavement edgeline.
  - Sideslope about 1:4.
  - Recoverable.

  Figure 2, *Typical Highway with Roadside Hazard Rating Equal to 2*
- **Rating = 3**
  - Clear zone about 3 m (10 ft) from pavement edgeline.
  - Sideslope about 1:3 or 1:4.
  - Rough roadside surface.
  - Marginally recoverable.

  Figure 3, *Typical Highway with Roadside Hazard Rating Equal to 3*
- **Rating = 4**
  - Clear zone between 1.5 and 3 m (5 to 10 ft) from pavement edgeline.
  - Sideslope about 1:3 or 1:4.
  - May have guardrail (1.5 to 2 m [5 to 6.5 ft] from pavement edgeline).
  - May have exposed trees, poles, or other objects (about 3 m or 10 ft from pavement edgeline
  - Marginally forgiving, but increased chance of a reportable roadside collision.

  Figure 4, *Typical Highway with Roadside Hazard Rating Equal to 4*
- **Rating = 5**
  - Clear zone between 1.5 and 3 m (5 to 10 ft) from pavement edgeline.
  - Sideslope about 1:3.
  - May have guardrail (0 to 1.5 m [0 to 5 ft] from pavement edgeline).
  - May have rigid obstacles or embankment within 2 to 3 m (6.5 to 10 ft) of pavement edgelin
  - Virtually non-recoverable.

  Figure 5, *Typical Highway with Roadside Hazard Rating Equal to 5*
- **Rating = 6**
  - Clear zone less than or equal to 1.5 m (5 ft).
  - Sideslope about 1:2.
  - No guardrail.
  - Exposed rigid obstacles within 0 to 2 m (0 to 6.5 ft) of the pavement edgeline.
  - Non-recoverable.

  Figure 6, *Typical Highway with Roadside Hazard Rating Equal to 6*
- **Rating = 7**
  - Clear zone less than or equal to 1.5 m (5 ft).

- o Sideslope 1:2 or steeper.
- o Cliff or vertical rock cut.
- o No guardrail.
- o Non-recoverable with high likelihood of severe injuries from roadside collision.

  Figure 7. *Typical Highway with Roadside Hazard Rating Equal to 7*

The following figures present photographs illustrating the seven roadside hazard rating categories.

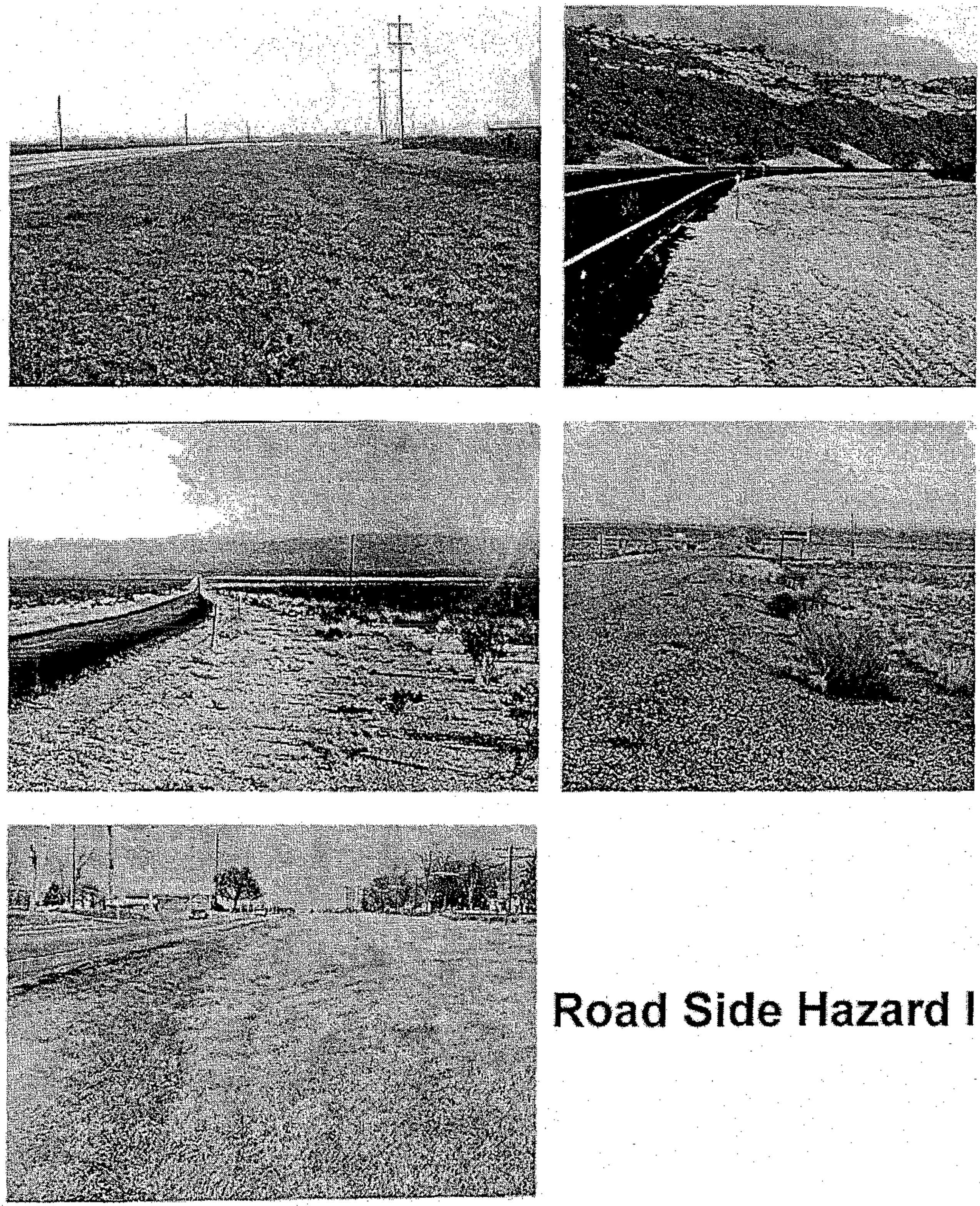
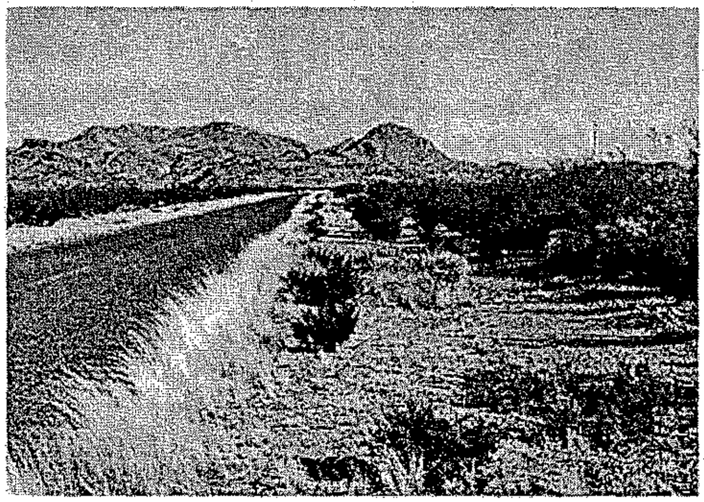
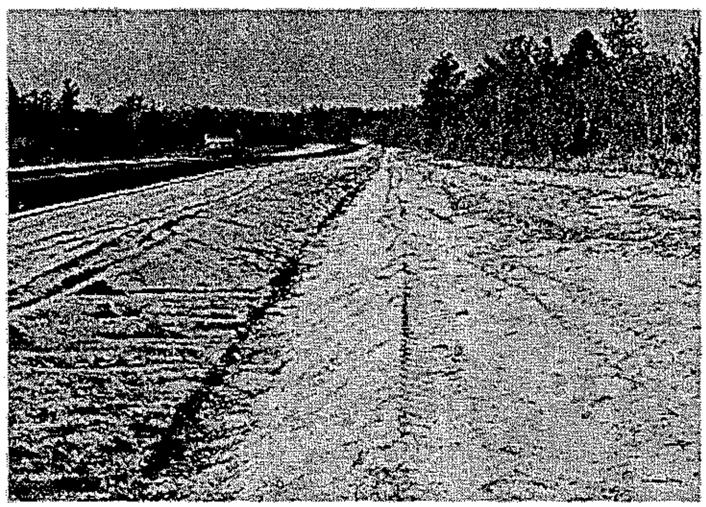
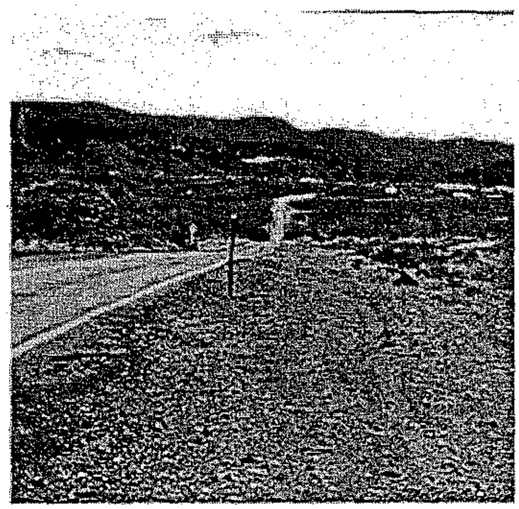
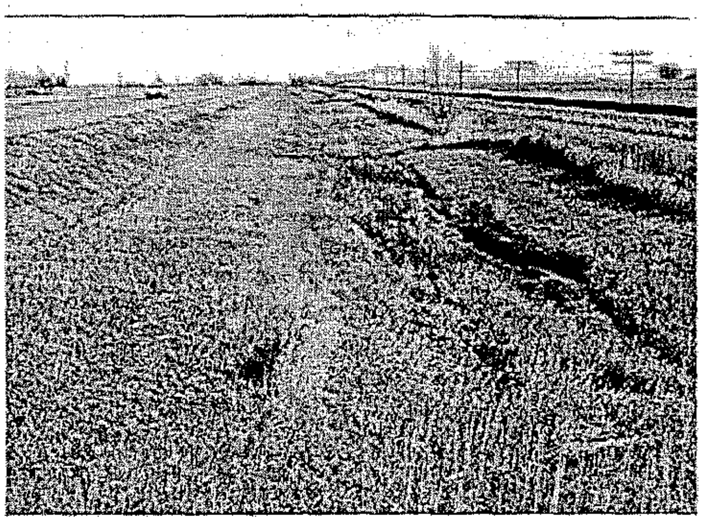


Figure 1 Typical Highway with Roadside Hazard Rating Equal to 1









Road Side Hazard I

Figure 2 Typical Highway with Roadside Hazard Rating Equal to 2

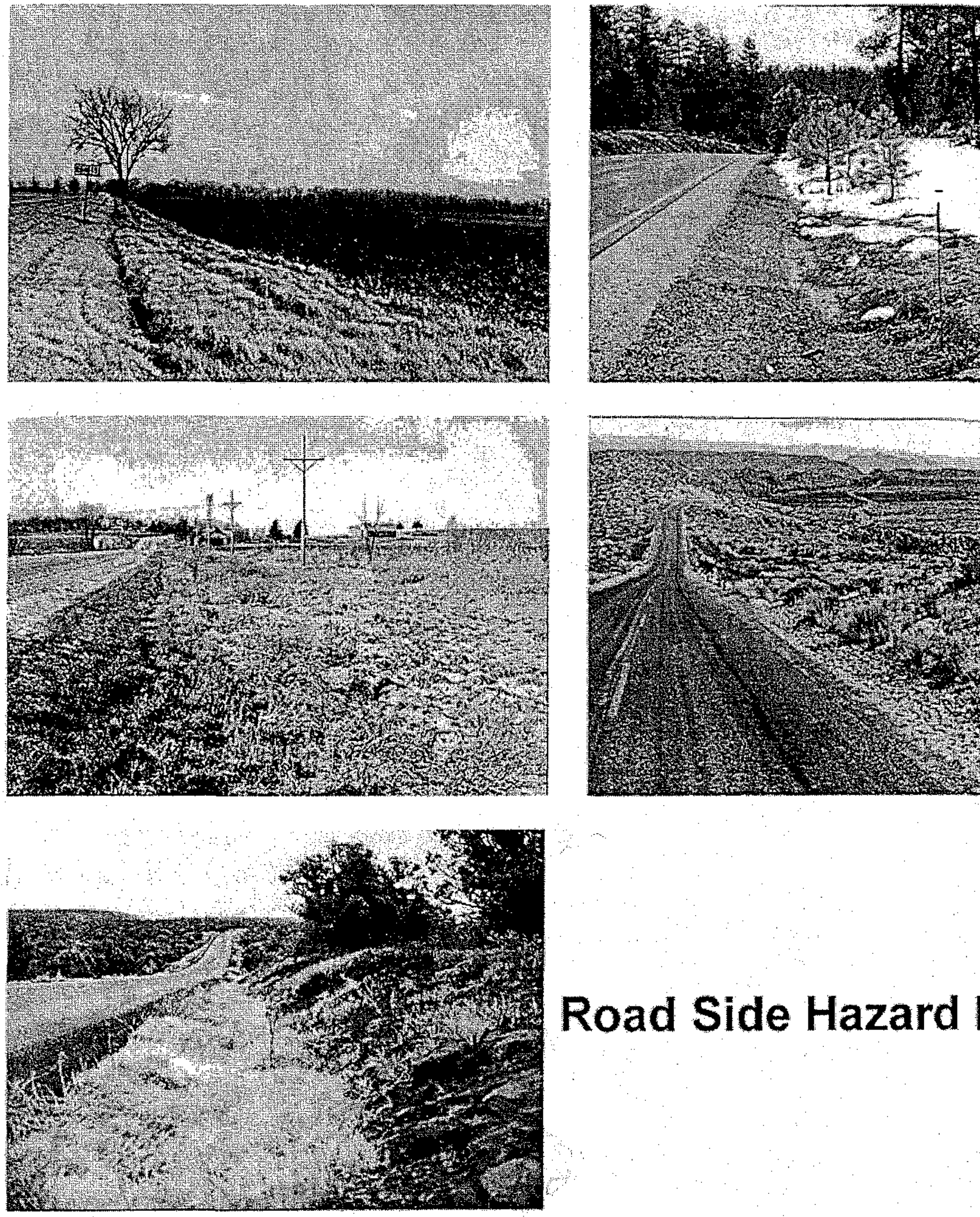


Figure 3 Typical Highway with Roadside Hazard Rating Equal to 3

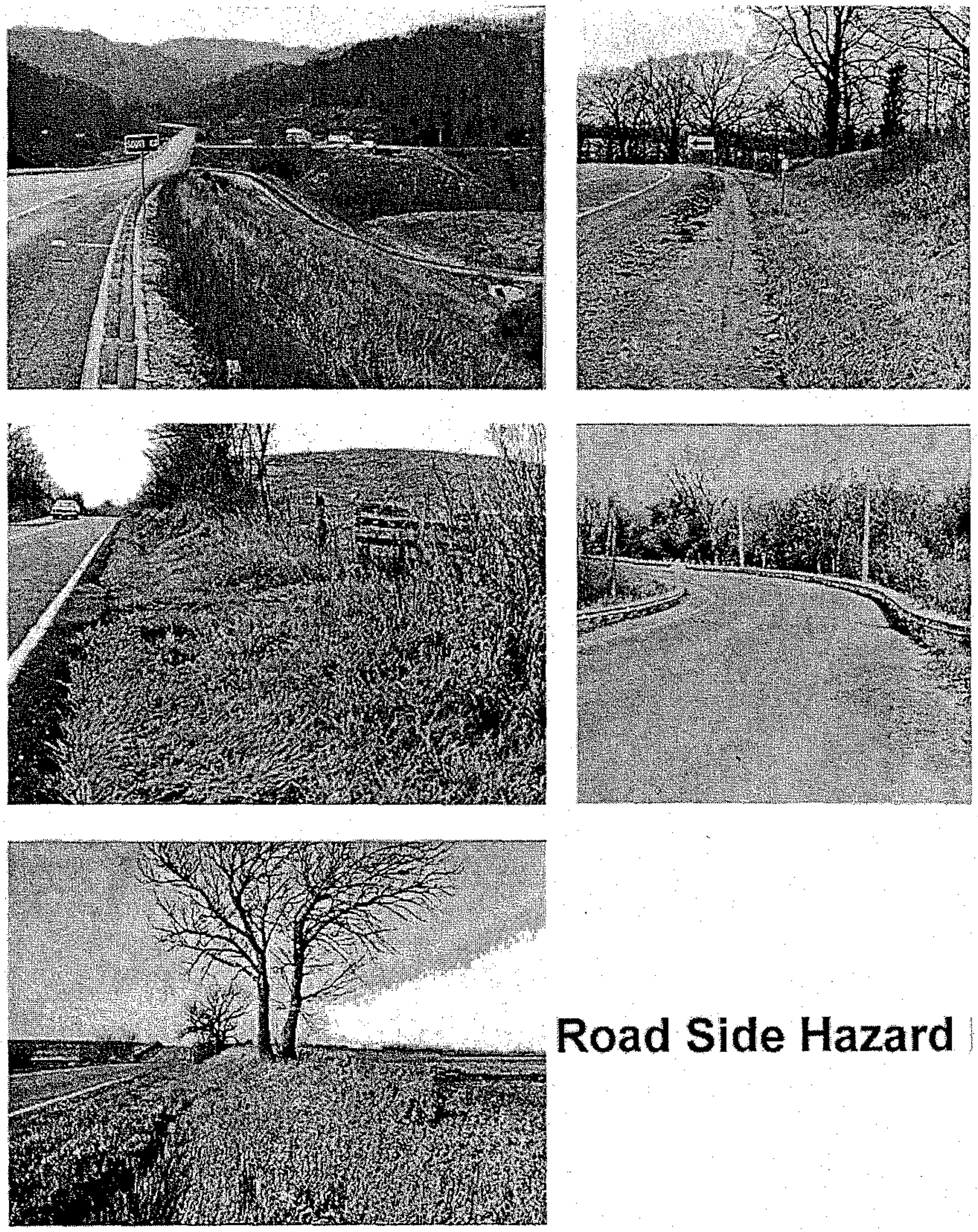


Figure 4 Typical Highway with Roadside Hazard Rating Equal to 4

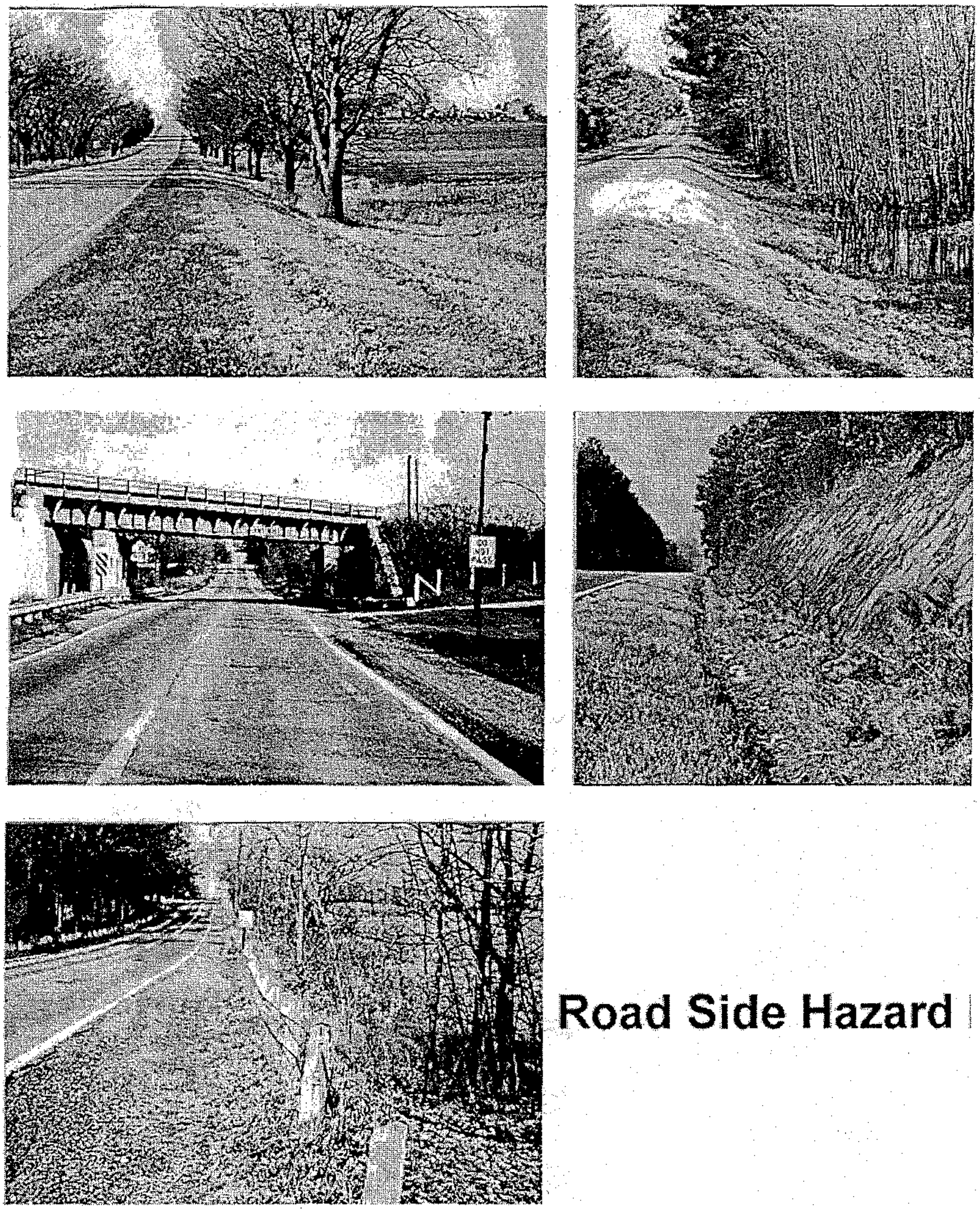


Figure 5 Typical Highway with Roadside Hazard Rating Equal to 5

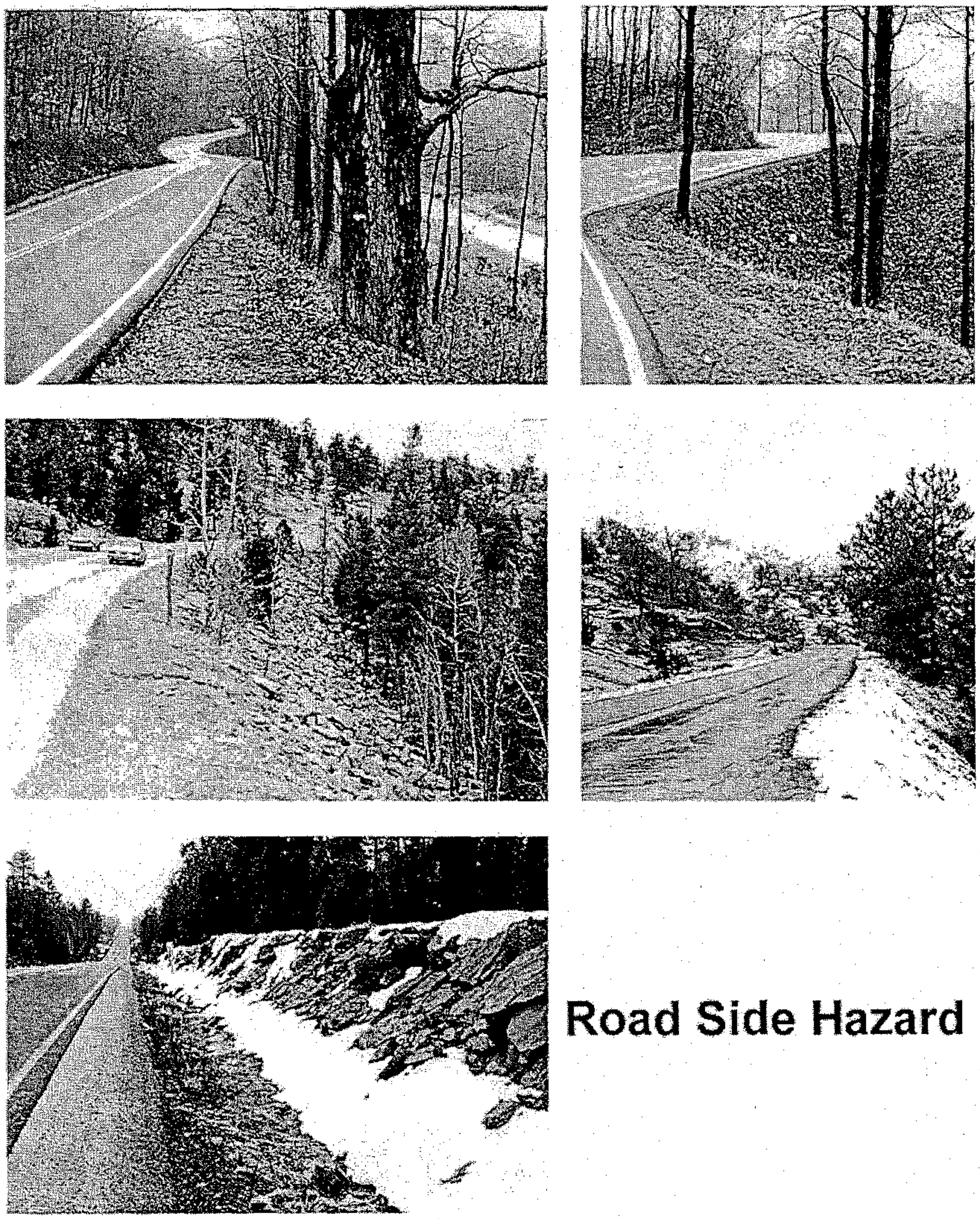


Figure 6 Typical Highway with Roadside Hazard Rating Equal to 6

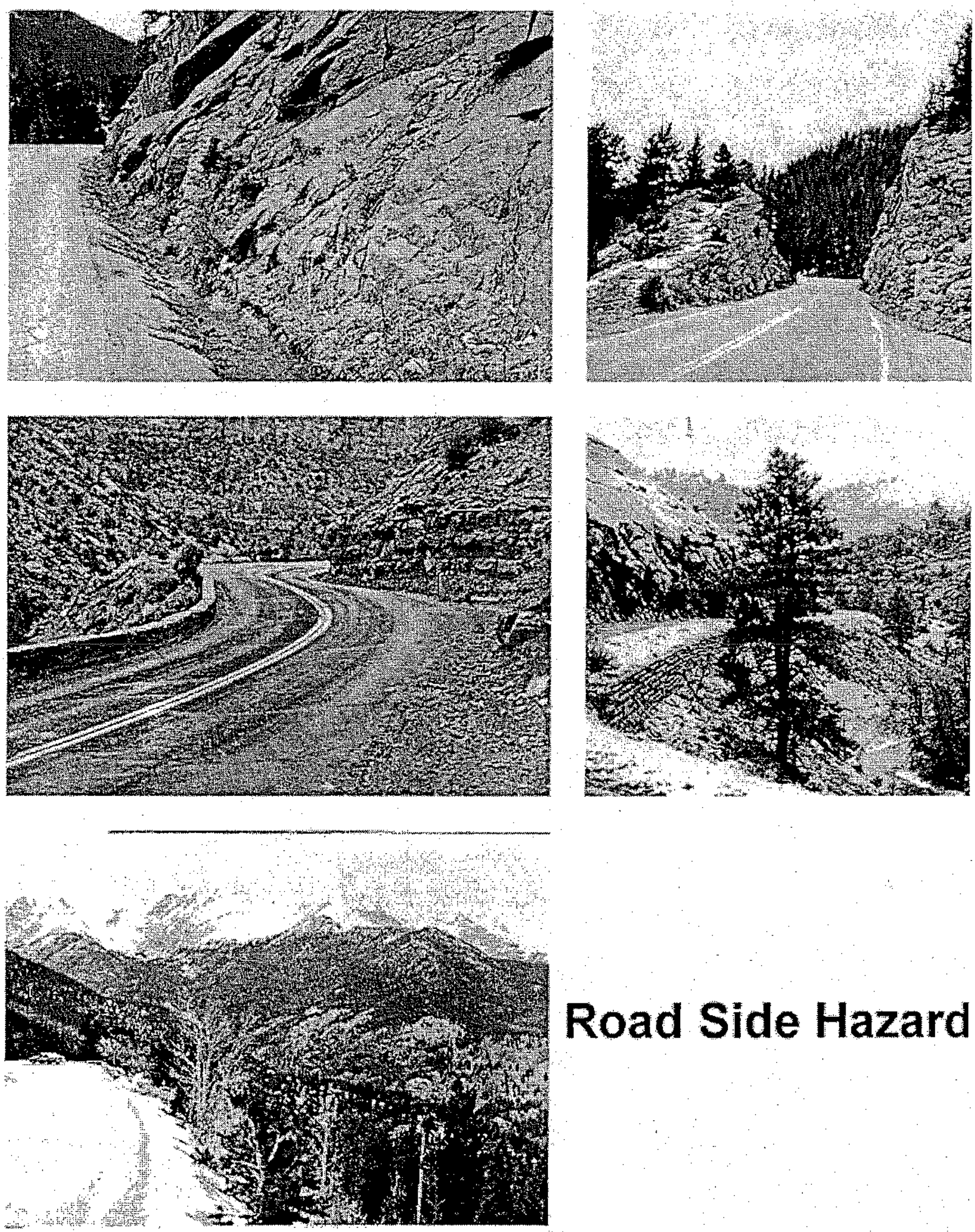


Figure 7 Typical Highway with Roadside Hazard Rating Equal to 7

Appendix B

Sample Printout of IHSDM Crash Expectation Module: Location 1000-1027

IHSDM Analysis Report

IHSDM Version: 2.05b; Mar 07, 2003 (11:27)
Date: October 5, 2004 7:28:23 AM EDT
Name: (trafficlab)
Organization: Kentucky Transportation Center
Telephone:
E-Mail:

Project: US 119 (unspecified)
Analysis: US 119 LOCATION 1000 AND 1027 (STA 997+00 - 1031+00)
Highway Information: US 119, chain: none (combined, file: US_119)

Table of Contents

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1. Crash Prediction Module

Crash Prediction Module Version: 1.00e (CPM Dec 13, 2002)

1.1 Segment Summary

Proposed Highway: US 119, chain none(combined, blob US_119)

Proposed Highway Segment Data

Segment #	Station Start	Station End	Length (ft)	Lane Width (ft) Right	Lane Width (ft) Left	Shoulder Width (ft) Right	Shoulder Width (ft) Left	Shoulder Type Right	Shoulder Type Left	Driveway Density (dwys/mi)	Roadside Hazard Rating	Horizontal Curve Number	Grade (%)	Passing Lane Right	Passing Lane Left	Center TWLTL
1	997+00.000	998+64.030	164.03	11.00	11.00	4.00	2.00	paved	paved	0.2	5	1	7.80	no	no	no
2	998+64.030	999+60.000	95.97	11.00	11.00	4.00	2.00	paved	paved	0.2	5	2	7.80	no	no	no
3	999+60.000	1000+29.430	69.43	11.00	11.00	4.00	2.00	paved	paved	0.2	5	2	8.81	no	no	no
4	1000+29.430	1001+50.000	120.57	11.00	11.00	4.00	2.00	paved	paved	0.2	5	-	8.81	no	no	no
5	1001+50.000	1001+71.840	21.84	11.00	11.00	4.00	2.00	paved	paved	0.2	5	-	8.81	no	no	no
6	1001+71.840	1003+84.140	212.30	11.00	11.00	4.00	2.00	paved	paved	0.2	5	3	8.81	no	no	no
7	1003+84.140	1018+13.490	1,429.35	11.00	11.00	4.00	2.00	paved	paved	0.2	5	-	8.81	no	no	no
8	1018+13.490	1019+33.730	120.24	11.00	11.00	4.00	2.00	paved	paved	0.2	5	4	8.81	no	no	no
9	1019+33.730	1019+71.330	37.60	11.00	11.00	4.00	2.00	paved	paved	0.2	5	-	8.81	no	no	no
10	1019+71.330	1021+46.590	175.26	11.00	11.00	4.00	2.00	paved	paved	0.2	5	5	8.81	no	no	no
11	1021+46.590	1024+00.000	253.41	11.00	11.00	4.00	2.00	paved	paved	0.2	5	6	8.81	no	no	no
12	1024+00.000	1024+69.570	69.57	11.00	11.00	4.00	2.00	paved	paved	0.2	5	6	8.81	no	no	no
13	1024+69.570	1025+30.000	60.43	11.00	11.00	3.65	2.70	paved	paved	0.2	5	7	8.81	no	no	no
14	1025+30.000	1025+69.640	39.64	11.00	11.00	3.35	3.30	paved	paved	0.2	5	7	8.85	no	no	no
15	1025+69.640	1026+00.000	30.36	11.00	11.00	3.15	3.70	paved	paved	0.2	5	8	8.85	no	no	no
16	1026+00.000	1026+50.000	50.00	11.00	11.00	3.00	4.00	paved	paved	0.2	5	8	8.85	no	no	no
17	1026+50.000	1027+50.000	100.00	11.00	11.00	2.75	3.50	paved	paved	0.2	5	8	9.60	no	no	no
18	1027+50.000	1027+91.240	41.24	11.00	11.00	2.25	2.50	paved	paved	0.2	5	8	7.83	no	no	no
19	1027+91.240	1028+00.000	8.76	11.00	11.00	2.04	2.09	paved	paved	0.2	5	9	7.83	no	no	no
20	1028+00.000	1028+50.000	50.00	11.00	11.00	2.00	2.00	paved	paved	0.2	5	9	7.83	no	no	no
21	1028+50.000	1029+25.240	75.24	11.00	11.00	2.00	2.00	paved	paved	0.2	5	9	7.18	no	no	no
22	1029+25.240	1031+00.000	174.76	11.00	11.00	2.00	2.00	paved	paved	0.2	5	10	7.18	no	no	no

Highway Segment Data from the CPM Engineer's Manual

Proposed Horizontal Curve Data

Horizontal Curve Number	Station Start	Station End	Length of Curve (ft)	Radius (ft)	Superelevation (%)	Design Speed (mph)	Spiral Transition
1	996+57.430	998+64.030	206.60	1,164.00	-10.00	40	none
2	998+64.030	1000+29.430	165.40	132.10	-10.00	40	none
3	1001+71.840	1003+84.140	212.30	737.80	-8.27	40	none
4	1018+13.490	1019+33.730	120.24	1,000.00	-9.67	40	none
5	1019+71.330	1021+46.590	175.26	521.10	-9.67	40	none
6	1021+46.590	1024+69.570	322.98	2,761.90	-9.67	40	none
7	1024+69.570	1025+69.640	100.07	287.00	-9.67	40	none
8	1025+69.640	1027+91.240	221.60	106.90	-9.67	40	none
9	1027+91.240	1029+25.240	134.00	284.50	-9.67	40	none

10	1029+25.240	1031+64.820	239.58	3,464.00	-9.67	40	none

Horizontal Curve Data from the CPM Engineer's Manual

Proposed Segment Traffic Volume

Segment #	Station		Analysis Period - ADT (v/day)			
	Start	End	2005	2006	2007	2008
1 to 22	997+00.000	1031+00.000	3,048	3,078	3,109	3,140

Interpolated values rendered in blue font.

Segment Traffic Volume from the CPM Engineer's Manual

1.2 Expected Crash Rates and Frequencies

Analysis Date: October 5, 2004
Project Name: US 119
Project Comment: unspecified
Analysis Name: US 119 LOCATION 1000 AND 1027
Analysis Comment: STA 997+00 - 1031+00
Proposed Highway: US 119
Chain: none
Comment: combined
Analysis Limits: 997+00.000 to 1031+00.000
Analysis Length: 0.6439 miles
Analysis Period: 2005 to 2008 (4 years)
Crash History Data: None
Unit System: English

Expected Crash Frequencies and Rates (Summary)

Total Crashes	5.6
Fatal and Injury Crashes (32%)	1.8
Property-damage-only Crashes (68%)	3.8
Average Future Road ADT (vehicles/day)	3094.0
Crash Rate per miles per year	2.17
Fatal and Injury Crash Rate per miles per year	0.7
Property-damage-only Crash Rate per miles per year	1.47
Total travel (million vehicle-miles)	2.91
Crash Rate per million vehicle-miles	1.92
Fatal and Injury Crash Rate per million vehicle-miles	0.62
Property-damage-only Crash Rate per million vehicle-miles	1.3

Expected Crash Frequencies and Rate from the CPM Engineer's Manual

1.3 Expected Crash Type Distribution

Analysis Date: October 5, 2004
Project Name: US 119
Project Comment: unspecified
Analysis Name: US 119 LOCATION 1000 AND 1027
Analysis Comment: STA 997+00 - 1031+00
Proposed Highway: US 119
Chain: none
Comment: combined
Analysis Limits: 997+00.000 to 1031+00.000
Analysis Length: 0.6439 miles
Analysis Period: 2005 to 2008 (4 years)
Crash History Data: None
Unit System: English

Expected Crash Type Distribution

Crash Type	Highway Segments	Intersections	Total
Single-vehicle accidents			
Collision with animal	1.7 (30.9%)	0.0 (0.0%)	1.7 (30.9%)
Collision with bicycle	0.0 (0.3%)	0.0 (0.0%)	0.0 (0.3%)
Collision with parked vehicle	0.0 (0.7%)	0.0 (0.0%)	0.0 (0.7%)
Collision with pedestrian	0.0 (0.5%)	0.0 (0.0%)	0.0 (0.5%)
Overturned	0.1 (2.3%)	0.0 (0.0%)	0.1 (2.3%)
Ran off road	1.6 (28.1%)	0.0 (0.0%)	1.6 (28.1%)
Other single-vehicle accident	0.2 (3.6%)	0.0 (0.0%)	0.2 (3.6%)
Total single-vehicle accidents	3.7 (66.4%)	0.0 (0.0%)	3.7 (66.4%)
Multiple-vehicle accidents			
Angle collision	0.2 (3.9%)	0.0 (0.0%)	0.2 (3.9%)
Head-on collision	0.1 (1.9%)	0.0 (0.0%)	0.1 (1.9%)
Left-turn collision	0.2 (4.2%)	0.0 (0.0%)	0.2 (4.2%)
Right-turn collision	0.0 (0.6%)	0.0 (0.0%)	0.0 (0.6%)
Rear-end collision	0.8 (13.9%)	0.0 (0.0%)	0.8 (13.9%)
Sideswipe opposite-direction	0.1 (2.4%)	0.0 (0.0%)	0.1 (2.4%)
Sideswipe same-direction	0.1 (2.6%)	0.0 (0.0%)	0.1 (2.6%)
Other multiple-vehicle collision	0.2 (4.1%)	0.0 (0.0%)	0.2 (4.1%)
Total multiple-vehicle collisions	1.9 (33.6%)	0.0 (0.0%)	1.9 (33.6%)
Total accidents	5.6 (100.0%)	0.0 (0.0%)	5.6 (100.0%)

Expected Crash Type Distributions from the CPM Engineer's Manual

1.4 Expected Crash Rates and Frequencies

Analysis Date: October 5, 2004
Project Name: US 119
Project Comment: unspecified
Analysis Name: US 119 LOCATION 1000 AND 1027
Analysis Comment: STA 997+00 - 1031+00
Proposed Highway: US 119
Chain: none
Comment: combined
Analysis Limits: 997+00.000 to 1031+00.000
Analysis Length: 0.6439 miles
Analysis Period: 2005 to 2008 (4 years)
Crash History Data: None
Unit System: English

Expected Crash Frequencies and Rates (Segment)

Intersection Name/Cross Road	Stations		Length (mi)	Expected no. of Crashes for analysis period	Expected Crash Rate			Expected no. of crashes/year for intersection
	From	To			/mi/yr	/million-veh-mi	/million entering veh	
	997+00.000	998+64.030	0.0311	0.2383	1.9180	1.6984		
	998+64.030	999+60.000	0.0182	0.6159	8.4712	7.5013		
	999+60.000	1000+29.430	0.0131	0.4520	8.5929	7.6091		
	1000+29.430	1001+50.000	0.0228	0.0736	0.8058	0.7135		
	1001+50.000	1001+71.840	0.0041	0.0133	0.8058	0.7135		
	1001+71.840	1003+84.140	0.0402	0.5321	3.3086	2.9298		
	1003+84.140	1018+13.490	0.2707	0.8725	0.8058	0.7135		
	1018+13.490	1019+33.730	0.0228	0.3588	3.9384	3.4875		
	1019+33.730	1019+71.330	0.0071	0.0230	0.8058	0.7135		
	1019+71.330	1021+46.590	0.0332	0.3471	2.6146	2.3153		
	1021+46.590	1024+00.000	0.0480	0.2554	1.3302	1.1779		
	1024+00.000	1024+69.570	0.0132	0.0701	1.3302	1.1779		
	1024+69.570	1025+30.000	0.0114	0.1395	3.0471	2.6982		
	1025+30.000	1025+69.640	0.0075	0.0912	3.0376	2.6898		
	1025+69.640	1026+00.000	0.0058	0.1388	6.0365	5.3453		
	1026+00.000	1026+50.000	0.0095	0.2282	6.0252	5.3354		
	1026+50.000	1027+50.000	0.0189	0.4655	6.1448	5.4413		
	1027+50.000	1027+91.240	0.0078	0.1907	6.1036	5.4048		
	1027+91.240	1028+00.000	0.0017	0.0206	3.1027	2.7475		
	1028+00.000	1028+50.000	0.0095	0.1177	3.1075	2.7518		
	1028+50.000	1029+25.240	0.0142	0.1755	3.0788	2.7263		
	1029+25.240	1031+00.000	0.0331	0.1618	1.2221	1.0822		

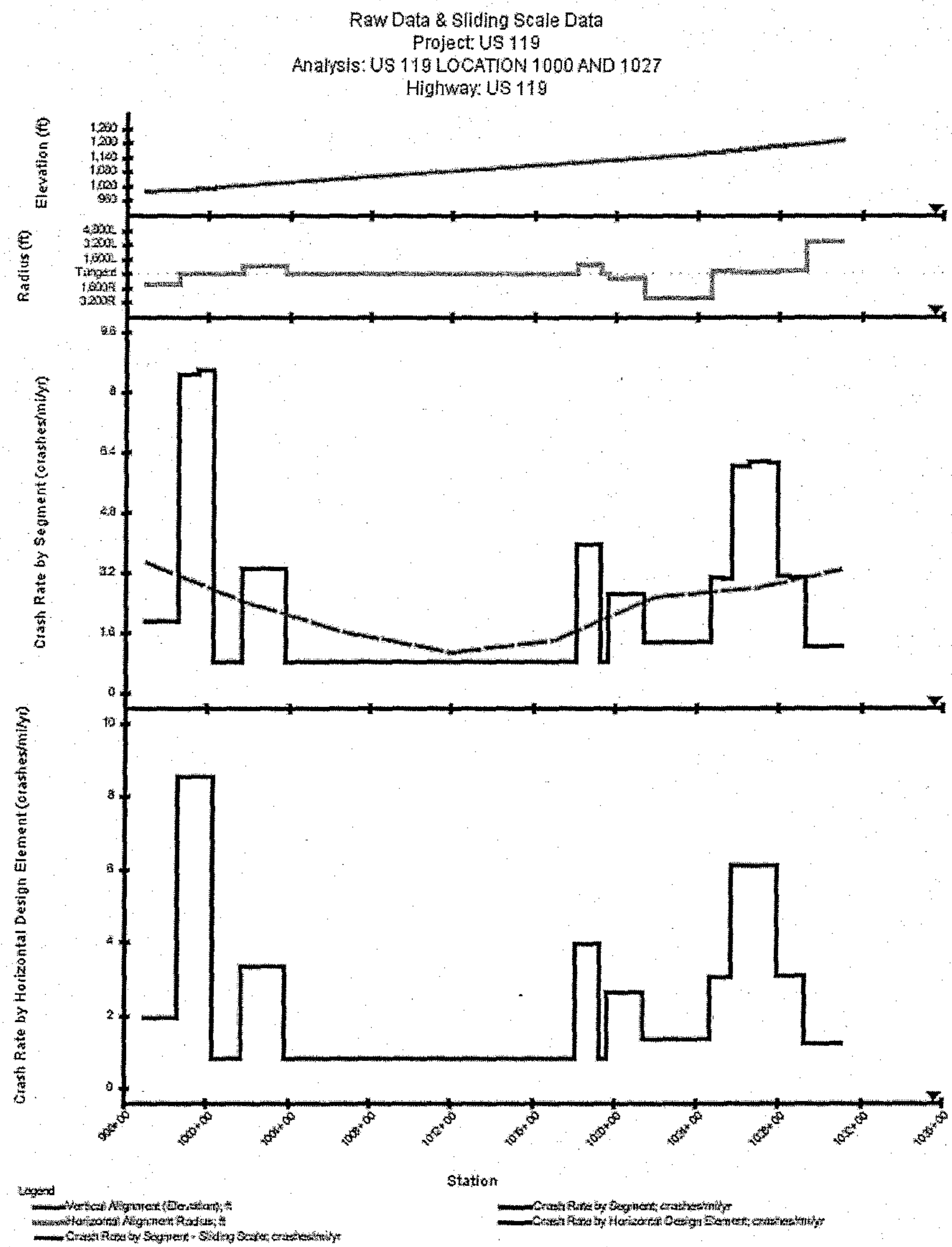
Expected Crash Frequencies and Rates by Horizontal Design Element

Design Element (Horizontal Curve Number or Tangent	Stations		Length (mi)	Expected no. of Crashes for analysis period	Expected Crash Rate	
	From	To			/mi/yr	/million-veh-mi
Curve 1	997+00.000	998+64.030	0.0311	0.2383	1.9180	1.6984
Curve 2	998+64.030	1000+29.430	0.0313	1.0679	8.5223	7.5465
Tangent	1000+29.430	1001+71.840	0.0270	0.0869	0.8058	0.7135
Curve 3	1001+71.840	1003+84.140	0.0402	0.5321	3.3086	2.9298
Tangent	1003+84.140	1018+13.490	0.2707	0.8725	0.8058	0.7135
Curve 4	1018+13.490	1019+33.730	0.0228	0.3588	3.9384	3.4875
Tangent	1019+33.730	1019+71.330	0.0071	0.0230	0.8058	0.7135
Curve 5	1019+71.330	1021+46.590	0.0332	0.3471	2.6146	2.3153
Curve 6	1021+46.590	1024+69.570	0.0612	0.3255	1.3302	1.1779
Curve 7	1024+69.570	1025+69.640	0.0190	0.2307	3.0433	2.6949
Curve 8	1025+69.640	1027+91.240	0.0420	1.0233	6.0953	5.3974
Curve 9	1027+91.240	1029+25.240	0.0254	0.3138	3.0911	2.7372
Curve 10	1029+25.240	1031+00.000	0.0331	0.1618	1.2221	1.0822

Results by Homogeneous Analysis Sections from the CPM Engineer's Manual

1.5 Crash Rate Plots

Graph: Crash Rates



Expected Crash Rate Plots from the CPM Engineer's Manual

Appendix C

Expected Crash Frequencies and Rates (Summary)														
			NO CLIMBING LANES											
	Existing	Exist. Lane +0	Exist. Lane and Shldr	12+4	12+3	11+4	12+2	11+3	11+1	Exist. Lane +0	12+0	10+4	10+2	10+0
Total Crashes	32.7	35.5	36.6	37	37.6	37.6	38.2	38.3	39.8	40.4	40.4	40.9	42.3	44.6
Fatal and Injury Crashes (32%)	10.5	11.4	11.7	11.9	12.1	12.1	12.3	12.3	12.8	13	13	13.1	13.6	14.3
Property-damage-only Crashes (68%)	22.2	24.1	24.8	25.1	25.5	25.6	26	26	27	27.4	27.4	27.8	28.7	30.3
Average Future Road ADT (vehicles/day)	3094	3094	3094	3094	3094	3094	3094	3094	3094	3094	3094	3094	3094	3094
Crash Rate per miles per year	4.05	4.38	4.52	4.57	4.65	4.65	4.73	4.73	4.92	4.99	4.99	5.05	5.22	5.52
Fatal and Injury Crash Rate per miles per year	1.3	1.41	1.45	1.47	1.49	1.49	1.52	1.52	1.58	1.6	1.6	1.62	1.68	1.77
Property-damage-only Crash Rate per miles per year	2.75	2.98	3.07	3.11	3.16	3.16	3.21	3.21	3.34	3.39	3.39	3.43	3.55	3.75
Total travel (million vehicle-miles)	9.13	9.13	9.13	9.13	9.13	9.13	9.13	9.13	9.13	9.13	9.13	9.13	9.13	9.13
Crash Rate per million vehicle-miles	3.58	3.88	4	4.05	4.12	4.12	4.19	4.19	4.35	4.42	4.42	4.48	4.63	4.89
Fatal and Injury Crash Rate per million vehicle-miles	1.15	1.25	1.29	1.3	1.32	1.32	1.34	1.35	1.4	1.42	1.42	1.44	1.49	1.57
Property-damage-only Crash Rate per million vehicle-miles	2.43	2.64	2.72	2.75	2.8	2.8	2.84	2.85	2.96	3	3	3.04	3.14	3.32