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EVALUATION OF THE APPLICABILITY OF THE INTERACTIVE HIGHWAY SAFETY DESIGN MODEL TO SAFETY AUDITS OF TWO-LANE RURAL HIGHWAYS

Prepared For:

Utah Department of Transportation
Research and Innovation Division

Submitted by:

UDOT Research and Innovation

Authored by:

UDOT Research and Innovation

March 2008

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Prepared For:

Utah Department of Transportation
Research and Innovation Division

Submitted by:

Brigham Young University
Department of Civil & Environmental Engineering

Authored by:

Mitsuru Saito, PhD, PE, F.ASCE
Kaitlin Chuo, EIT

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16. Abstract

The Interactive Highway Safety Design Model (IHSDM) is a suite of software developed by the Federal Highway Administration (FHWA) for monitoring and analyzing two-lane rural highways in the United States. Among the six modules available in IHSDM, two were chosen for evaluation because of their applicability to audit safety of the two-lane rural highways in Utah, namely the Crash Prediction Module (CPM) and the Intersection Review Module (IRM). It was found that the CPM can produce reasonably reliable crash predictions if appropriate input data, especially alignment data, reflect the existing conditions at reasonable accuracy and engineering judgment is used. Using crash records available from the crash database developed by the Utah Department of Transportation (UDOT) and CPM's crash prediction capability, UDOT's traffic and safety engineers can locate "hot spots" for detailed safety audit, thus making the safety audit task more focused and effective. Unlike the CPM, the outputs of the IRM are qualitative and include primarily suggestions and recommendations. They will help the traffic and safety engineers what to look for as they visit the sites, such as a lack of stopping sight distance and a lack of passing sight distance. Based on the findings of the study, it is concluded that the CPM and IRM of IHSDM could be a useful tool for engineering decision-making during safety audits of two-lane rural highways. However, the outputs from these modules demand knowledge and experience in highway design.

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Name	***Title & Organization***
Doug Anderson	Project Manager, R&D Division, UDOT
Robert Hull	Traffic Safety Engineer, Traffic & Safety Division, UDOT
John Leonard	Operations Engineer, Traffic & Safety Division, UDOT
Darin Duersch	Traffic & Safety Engineer, UDOT Region 1
Robert Miles	Former Traffic & Safety Engineer, UDOT Region 2
Troy Peterson	Traffic & Safety Engineer, UDOT Region 2
Tam Southwick	Traffic & Safety Engineer, UDOT Region 2
Doug Bassett	Traffic & Safety Engineer, UDOT Region 3
Troy Torgersen	Traffic & Safety Engineer, UDOT Region 4
Roland Stanger	Federal Highway Administration
Monte Warr	UDOT Photolog specialist
Jeff Ericson	UDOT Photolog specialist

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EXECTUIVE SUMMARY

The Federal Highway Administration (FHWA) reported that two-lane rural highways comprise 77 percent of the nation's highway systems and they account for 44 percent of the nation's fatal crashes (FHWA 2006). Keeping two-way rural highways safe is an important task of many state departments of transportation. As one method to proactively identify potential problems on highway sections and intersections, roadway safety audits are conducted. However, sending several experts to the study sites without clear ideas is simply costly and time consuming. Hence, a method that will help transportation engineers set a clear goal for inspection prior to field inspections has been sought.

FHWA has worked on the development of the Interactive Highway Safety Design Model (IHSDM) in an attempt to help highway engineers design safe two-lane highways and to help safety engineers efficiently analyze safety impacts of alternative designs (FHWA 2006). The IHSDM consists of six modules: Policy Review Module (PRM), Crash Prediction Module (CPM), Design Consistency Module (DCM), Traffic Analysis Module (TAM), Intersection Review Module (IRM), and Driver/Vehicle Module (DVM) (still under construction).

Only a limited amount of research has been conducted to evaluate its practicability and reliability. This study was therefore conducted to determine if IHSDM can be adopted into the engineering decision making process during safety audits of two-way rural highways within the Utah Department of Transportation (UDOT). Among the six modules, two modules, CPM and IRM, were chosen for evaluation because of their potential applicability to safety audits of the two-lane rural highways in Utah.

Both CPM and IRM require, at minimum, horizontal and vertical alignments. However, plans of two-way rural highways were practically nonexistent because they were constructed many years ago. Furthermore, reconstruction and/or rehabilitation works that might have taken place to these highways; hence, finding their alignments was practically impossible. Hence, a new method was developed for this study to create surrogate alignments using GPS data collected by UDOT. This method helps the engineers to create surrogate alignments of any two-way rural highways under study as long as GPS data for each direction of the highway sections are available. This new method for creating surrogate alignments is one notable contribution of this study for expanding the use of IHSDM to safety audits of two-way rural highways.

Findings

The analyses done in the study indicate that the CPM has the ability to duplicate similar trends in number of crashes, if the quality of the input data is maintained. A large number of crashes involving wild animals may negatively affect the ability of the CPM as demonstrated by one of the study sections and engineers need to be cautious about the outcomes from the CPM. As for the IRM, the outputs of the module include suggestions and recommendations to improve the intersections and they require engineering judgment in interpreting them and in selecting improvements presented.

Based on the comparison of the trends in the number of crashes with and without crash history along the highway segments of the three study sections and the mean difference between the number of crashes with and without crash history, the CPM is found to be a capable and useful tool for the highway and safety engineers as they prepare for safety audits of two-way rural highways. The finding on the differences in number of crashes with and without crash history is important. This means the CPM can be used to estimate crash occurrences for alternative improvements to the existing sections, where crash histories for the alternatives do not exist. The IRM, on the other hand, can function like a knowledge-based safety inspection assistant by providing diagnostic statements and offering potential crash mitigation measures. It should be noted however that interpreting the outputs from these modules of IHSDM requires knowledge and experience in highway design and familiarity with *A Policy on Geometric Design of Highway and Streets* by AASHTO (2004).

Recommendations

The Users' Manual of IHSDM states, "IHSDM is intended as a supplementary tool to augment the design process…This tool is NOT a substitute for engineering judgment…" (FHWA 2006). IHSDM is not to be used as a replacement to engineering experience and decision-making. This notion is especially important when using the CPM, where future crash rates are predicted for the future; the crash rates predicted by the CPM should never be taken as specific numbers of crashes that may take place but they should be taken as indicators of trends in crash occurrence. Also, since the outputs of the IRM are suggestions and recommendations produced by the equations and pre-defined procedures in the program, they need to be used with caution and should not be accepted blindly. Study sites must be visited and their suggestions and recommendations be evaluated for their appropriateness.

Traffic safety engineers at UDOT can incorporate the CPM and IRM modules of IHSDM into their safety audit routine. Running these modules will help them identify potential "hot spots" that require special attention before they send a group of experts to the field. This will help them use their time and resources efficiently and effectively.

Because IHSDM can be downloaded free of charge, the cost for the UDOT engineers to utilize the software is practically none. The software is self-explanatory and relatively easy to learn; however, receiving training on the software provided by FHWA will certainly help the engineer become confident in the use of the software. Since only the CPM and IRM modules of IHSDM were evaluated in this study, the capability and usefulness of the other modules are yet unknown. It is recommended that UDOT engineers explore all six modules of IHSDM to fully appreciate the power of the software and identify how this software can be used to improve the conditions of two-way rural highways.

As for the features of the CPM, the crash prediction models implicitly include the effect of animal-related crashes. There is no feature to adjust the situation for highway sections with over-represented occurrences of animal-related crashes. Therefore, it is recommended to investigate if animal-related crashes can be excluded in order to analyze the highway sections purely from the geometric conditions of the highways.

IHSDM allows the users to calibrate prediction models in the CPM to better reflect the local conditions. This issue was outside the scope of this study; however, such calibration efforts may increase the module's crash prediction capability. It is recommended to conduct a study to determine the values of the calibration factor included in the crash prediction model to make the CPM more responsive to the drivers on Utah's two-way rural highways.

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1 Introduction

Due to the importance of rural highways and the role they play in state's highway network, monitoring their safety has been a major task for transportation engineers in the United States. Throughout time, transportation engineers have been using different methods available to them to conduct safety audits of rural highways. As the population grows and as the trips made on rural highways increases, a more advanced, systematic method of monitoring the safety of rural highways is urgently needed. The Federal Highway Administration (FHWA) recognized this need and developed a suite of software programs called the Interactive Highway Safety Design Model (IHSDM) in order to provide digital assistance for analyzing safety problems of existing and planned rural two-lane highways.

1.1 Purpose and Scope of the Study

Reducing crashes on highways has always been one of the most important tasks for transportation engineers while they are in the process of planning, design, construction, and maintenance. Providing a safe driving environment is indeed not only a responsibility, but also the highest priority for all highway projects.

Traditionally transportation engineers have to manually check their design to see if all the values used for design are in compliance with all the federal, state, and local policies, or if average drivers and pedestrians could comprehend their design. FHWA recognized the deficiency of the traditional method and the need for a more systematic method that assists transportation engineers using modern technologies, and began developing IHSDM in 1995. A concise description of IHSDM is posted in its official website, "IHSDM is a decision-support tool. It checks existing or proposed two-lane rural highway designs against relevant design policy values and provides estimates of a design's expected safety and operational performance. IHSDM results support decision making in the highway design process," (FHWA 2006). As IHSDM was further developed, the Utah Department of Transportation (UDOT) decided to evaluate IHSDM to see if it could be incorporated in their safety audit program for two-lane rural highways.

A Road Safety Audit (RSA) is "the formal safety performance examination of an existing or future road or intersection by an independent, multidisciplinary team. It qualitatively estimates and reports on potential road safety issues and identifies opportunities for improvements in safety for all road users," (FHWA 2008). The goal of an RSA is to answer the following two questions (FHWA 2008):

- What elements of the road may present a safety concern: to what extent, to which road users, and under what circumstances?
- What opportunities exist to eliminate or mitigate identified safety concerns?

The purpose for this research is to evaluate the capability of IHSDM in helping transportation engineers to locate highway segments with high crash rates and to predict crash rates for improvement alternatives. After discussing the research with the members of the Technical Advisory Committee (TAC), which was set up for the study and consisted of selected UDOT engineers, two IHSDM modules were selected for evaluation: the Crash Prediction Module (CPM) and the Intersection Review Module (IRM).

The scope of this study includes the analysis of three two-lane rural highway sections by CPM and two intersections by IRM in order to test their applicability to UDOT's safety audit process. Some of the selected highway segments have had significantly high crash rates; therefore, this study also provides UDOT engineers an evaluation of these problematic highway sections.

1.2 The Current Application of IHSDM

UDOT is not the first public agency to recognize the potential use of IHSDM. There have been several engineering projects that have adopted IHSDM in their safety evaluations. Mike Dimaiuta, the IHSDM development project manager at the Turner-Fairbank Highway Research Center in McLean, Virginia (Dimaiuta 2006), provided the authors of this report a list of state DOTs and other organizations that have already utilized IHSDM to enhance the safety of two-lane rural highways. Table 1-1 lists some of the engineering projects that have used IHSDM.

Table 1-1: Engineering Projects that Adopted IHSDM

Project Name	Organization(s)	Web Address
Fernan Lake Road Improvement Project	FHWA Western Federal Land	http://www.wfl.fhwa.dot.gov/projects/fernan/
US 119 Pine Mountain Improvements	Kentucky Transportation Center for the Kentucky Transportation Cabinet	http://www.ktc.uky.edu/Reports/KTC_04_31_FR121_02_2I.pdf
Statewide Projects	Washington Department of Transportation	http://www.wsdot.wa.gov/eesc/design/ihsdm/
Indian Reservation Roads (IRR) Database and Model Development, Task 7	Mountain-Plains Consortium (MPC)	http://www.mountain-plains.org/research/2006proj/index.php?proj=MPC-3
Road Safety Audits: The FHWA Case Study Program	Hamilton Associates, BMI and FHWA	http://www.gdhamilton.com/resources/TRB06.pdf
Application of the IHSDM: A Case Study	Kittelson & Associates, Inc.	http://pubsindex.trb.org/document/view/default.asp?lbid=760602
Highway 26 Road Safety and Operational Review	Delphi-MRC	http://www.delphimrc.com/searchpro/index.php?q=IHSDM&search=Search

In these projects, IHSDM was used mostly to evaluate road geometric design and perform crash prediction analysis. For example, the US-119 Pine Mountain Improvements Project used IHSDM to evaluate the safety of the road after implementing changes in alignments, and the road safety audits conducted by the FHWA Case Study Program also utilized the features of IHSDM to conduct safety audits.

1.3 Organization of the Report

Chapter 1 introduces the objectives and procedures taken in the study. Chapter 2 presents the findings from the literature review conducted as part of the study to provide readers with some background knowledge and the structure of IHSDM. Chapter 3 discusses the analysis procedures developed specifically for the study. Chapter 4 records the findings from the CPM evaluation of the three two-lane rural highway sections, followed by Chapter 5 which presents the results of the application of the IRM module for two rural intersections. Finally, Chapter 6 presents conclusions and recommendations.

2 Literature Research

IHSDM was developed by the Safety Research and Development Program of FHWA. The purpose of IHSDM is to evaluate existing and proposed two-lane rural highways by providing quantitative information to highway designers and safety engineers. Two-lane rural highways comprise 77 percent of the nation's highway systems and they account for 44 percent of the nation's fatal crashes (FHWA 2006). FHWA has developed IHSDM in an attempt to help highway engineers design safe two-lane highways and to help safety engineers efficiently analyze safety impacts of alternative designs (FHWA 2006). The latest version of IHSDM was released in December 2007 and is available for download online to the public free-of-charge. However, the version used for this study was a 2006 version, which was available at the time this study began.

During the literature search, it was recognized that there was a lack of studies that had been conducted for evaluating the applicability of IHSDM to safety audit, partially because IHSDM was relatively new to the transportation engineering community. The articles that were written about IHSDM were mainly to introduce the features of the software or validate the methods or modules contained in the program. These are undoubtedly important topics to be presented; however, for the transportation engineering community to recognize the usefulness of IHSDM more practical applications of ISHDM are needed.

2.1 The Overview of IHSDM

The overview of the IHSDM cannot be better presented than by Raymond Krammes, the highway research engineer in the Office of Safety Research & Development of FHWA (FHWA 2006):

“ *IHSDM is a suite of software analysis tools for evaluating safety and operational effects of geometric design decisions on two-lane rural highways.*”

Figure 2-1 shows a screenshot of IHSDM. IHSDM’s goal is to provide transportation engineers a tool that will help them design safe two-lane rural highways. IHSDM requires proper training and the understanding of highway geometric design and traffic safety issues related to two-lane rural highways. Also, IHSDM supports all major highway design software programs such as GEOPAK and CAiCE, and the engineering programs that are developed Bentley and Autodesk; alignment data can be transferred directly from these software programs into IHSDM (FHWA 2006).

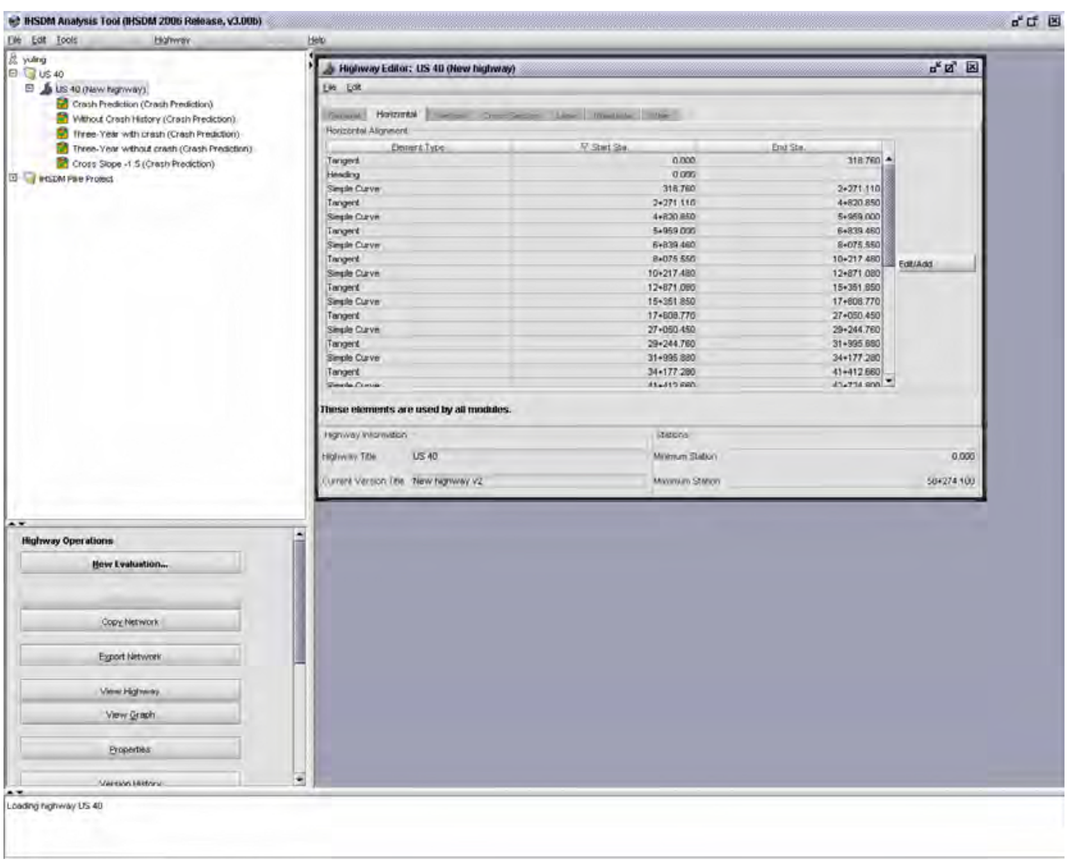


Figure 2-1: IHSDM Screenshot

The design of two-lane rural highways can be evaluated by the six modules of IHSDM: Policy Review Module, Crash Prediction Module, Design Consistency Module, Traffic Analysis Module, Intersection Review Module, and Driver/Vehicle Module. The user does not need to use all of these modules. Depending on the objective of evaluation, the user can select the modules he or she needs. Each module is briefly discussed in the following subsections.

2.1.1 Policy Review Module (PRM)

The PRM module reviews the roadway design by checking the design values with the standard policies specified in *A Policy on Geometric Design of Highway and Streets* by the American Association of State Highway and Transportation Officials (AASHTO) (AASHTO 2004). The module checks four highway design categories: cross sections, horizontal alignment, vertical alignment, and sight distance. The cross section category checks the traveled way width and its cross slope, auxiliary lane width and its cross slope, shoulder width and its cross slope, cross slope rollover on curves, and bridge width. The horizontal alignment category evaluates radius of curvature, superelevation, compound curve ratio, and length of horizontal curve. The vertical alignment category verifies tangent grade length and vertical curve length. The sight distance category checks stopping sight distance, passing sight distance, and decision sight distance. Additional checks are done for clear zone, roadside slope, normal ditch design, and superelevation transition.

The PRM module is a digitized policy review that checks 1990, 1994, 2001, and 2004 versions of AASHTO's *A Policy on Geometric Design of Highway and Streets*. The module also allows users to modify some of the policy tables to reflect unique policies that differ from the AASHTO policies. However, policies that are not quantitative are not yet translated into this electronic policy check.

2.1.2 Crash Predication Module (CPM)

The CPM estimates the number and rate of crashes by evaluating the geometric design and traffic flow characteristics of two-lane rural highways. The crash prediction algorithm consists of three components: base models, calibration factor, and accident modification factors (AMFs).

In CPM, the equations 2-1 and 2-2 are used to predict the number of crashes for highway segments (FHWA 2006):

$$N_{rs} = N_{br} C_r AMF_1 AMF_2 AMF_3 AMF_4 AMF_5 AMF_6 AMF_7 AMF_8 AMF_9 \quad \textbf{(2-1)}$$

$$N_{br} = (ADT_n)(L)(365)(10^{-6})\exp(-0.4865) \quad \textbf{(2-2)}$$

Where:

N_{rs} = predicted number of total highway segment crashes per year,

N_{br} = predicted number of total highway segment crashes per year for nominal or base conditions,

C_r = calibration factor for highway segments,

$AMF_1, ..., AMF_9$ = accident modification factors for highway segments,

ADT_n = average daily traffic volume for specified year n (veh/day),

L = length of highway segment (mi).

The crash rate is obtained by dividing N_{rs} by the exposure value expressed by $(ADT_n)(L)(10^{-6})$, resulting in crashes per million vehicle miles of travel (MVMT). Detailed discussions of the prediction models are found in the on-line Help Documents included in the IHSDM software (FHWA 2006).

Each base model was developed and calibrated with data collected from one or two states. The AMFs further adjust the outcome of base models taking into account particular road design and traffic characteristics. For an existing highway, the empirical Bayes method is used to combine model estimations with the crash history data of the highway section under study. For further information on the specific equations and procedural guideline of CPM the reader is suggested to refer to the Engineering Manual accessed through the Help feature of the IHSDM software (FHWA 2006).

As safety is the number one priority in highway design, CPM is the most often used module, and at the same time the most controversial module of IHSDM. This concern is reflected in the bulletin board of the official support center; the majority of concerns the center has received is about CPM (Dimaiuta 2006). One of the most important pieces of advice for CPM users, given by the IHSDM program manager, is that users recognize the fact that there is no crash prediction method, model, system, or program that can ever be 100 percent perfect. Hence, CPM users must be capable of properly interpreting the outcome of CPM analyses (Dimaiuta 2006).

In the field of transportation planning several methods have been used over time in an attempt to predict crash rates. Examples of this type of usage includes an analysis of historical data of road segments with similar characteristics, before-and-after studies, regression analyses of crash rates, and so on. Just like any other prediction methods, crash prediction models have its strengths and weaknesses. The CPM is based on the well-known approaches of the past, and they inevitably inherited the strengths and weaknesses of these methods. Kinney (2005) said, “One of the author’s professors used to say, ‘all models are wrong, some are useful.’ IHSDM appears to satisfy both parts of this statement.”

Crash prediction models used in CPM are based on a negative binomial regression analysis that ensures sensitivity to site-specific geometric design and traffic control features. The CPM is more useful in identifying high crash locations than estimating specific crash frequency or rates. The ability of the CPM in predicting crash occurrences increases if both historic crash data of either a similar site or the target road itself and correct geometric design data of the highway section under study are available as long as geometric conditions remain the same in the future (Dimaiuta 2006).

One major complaint that the IHSDM support center has received is the large amount of input data required by the CPM module to produce reliable estimates. Another complaint by many engineers is that IHSDM only uses a simplified module of roadside information, which they consider inefficient in representing realistic roadside conditions. Also, the interaction among roadway geometric design features is neglected. This issue was pointed out by the expert panel that developed AMFs but the problem has not been resolved (Dimaiuta 2006).

The bottom line is that engineers need to be aware that CPM outputs should be used as a reference instead of being used as absolute values. Kinney (2005) stated, “It is important that we recognize that IHSDM is a decision tool which is not meant to be a substitute for engineering judgment."

2.1.3 Design Consistency Module (DCM)

The Design Consistency Module (DCM) provides the evaluation of potential speed inconsistencies. The module uses a speed-profile model to perform the task and estimates 85^{th} percentile, free-flow, and passenger vehicle speeds at different points along a roadway. The speed-profile model checks estimated 85^{th} percentile speeds on curves (horizontal, vertical, and horizontal-vertical combinations), desired speeds on long tangents, acceleration and deceleration rates for entering and exiting curves, and an algorithm for estimating speeds on vertical grades (FHWA 2006).

The major strength of DCM is that it provides quantitative measures for evaluating the consistency of traveling speed along a highway and takes into account the effect of both horizontal and vertical alignments on operating speed. However, because the equations used in the module were derived from the data collected in a few selected states – Texas, Washington, Oregon, Michigan, New York, and Pennsylvania – the applicability of the equations to highways in the other states is still under scrutiny. Another concern about the DCM is that it is only applicable to highways with relatively higher speeds. For highways with speed limit less than 50 mph the module may not be appropriate (Dimaiuta 2006).

2.1.4 Traffic Analysis Module (TAM)

The Traffic Analysis Module (TAM) contains TWOPAS – a microscopic traffic simulation model for two-lane rural highways. TWOPAS has the capability to simulate any combinations of passing and climbing lanes, no passing zones, sight restrictions, curves, and grades and takes into account the effects of road geometry, driver characteristics and their driving preferences, vehicle size and performance characteristics, and the presence of oncoming and same-direction vehicles that are in sight at any given time (FHWA 2006).

However, the TAM takes no considerations for turning lanes, intersections, shoulders, or any other forms of interruption to two-lane highway operation. Thus, for the TAM to work on a two-lane highway that contains interludes, the highway needs to be split into segments that do not have any interruptions within them (FHWA 2006).

2.1.5 Intersection Review Module (IRM)

The IRM performs a diagnostic review to systematically evaluate an intersection design for typical safety concerns. The module evaluates intersections from four perspectives: intersection configuration, horizontal alignment, vertical alignment, and intersection sight distance (FHWA 2006).

The IRM provides a comprehensive review of an intersection design to diagnose geometric factors, identify potential concerns about safety and possible solutions for these concerns, and consider the overall outcome of all geometric design elements (FHWA 2006).

Because of its unique nature, the IRM stands independent from all other modules. The IRM requires a different set of data, file, and evaluation settings.

2.1.6 Driver/Vehicle Module (DVM)

The DVM evaluates how a driver would react and respond to the roadway design while operating a vehicle and also identifies if the roadway condition may increase the potential for the driver to lose control. This module consists of two models: the driver performance model (DPM) and the vehicle dynamics model (VDM). The DPM estimates elements such as perception, speed decision, path decision, attention, speed control, path control, and other elements that affect driver’s performance while the VDM estimates elements such as lateral acceleration, friction demand, and rolling moments (FHWA 2006)..

The DPM was not available at the time of this report. According to the program developer, the DPM can closely mimic the effects of curve radius and curve deflection on driver’s speed choice, but how “close” the model can mimic the driver’s decision making will remain to be seen until the model is released and tested with real-life situations. For instance, different types of drivers still need to be represented, but the current module does not consider such diversity, and the assumption that a given driver negotiates all curves is not realistic (FHWA 2006).

2.2 Literature Research

As mentioned at the beginning of this chapter, IHSDM has been on the market only for a relatively short period of time; hence, the amount of literature on IHSDM's applications is yet small. Most of the literature available are reviews of the reliability of the mathematical equations used in the models, the model logic, or the consistency of the modules of IHSDM (Levison et al. 2002, Louisell et al. 2006, Oh et al. 2003). There is a lack of literature that discusses the application aspect of IHSDM. Only a small number of reports were available for the study. For example, Kinney gave descriptions of his encounter with IHSDM on a 3R (Resurfacing, Restoration, and Rehabilitation) project in Anchorage, Alaska (Kinney 2005). He used IHSDM to evaluate the comparison made between the traditional 3R methods and 3R alternative methods. Kinney (2005) stated that "IHSDM is a good tool for evaluating two-lane [rural highway] alternatives. It is relatively easy to use and comes with a complete set of manuals to assist the user in preparing models. The IHSDM model is applicable to new and 3R analysis…the Policy Review Module and the Design Consistency Module are excellent tools in evaluating new designs or multiple alternatives."

Figure 2-2 is a summary of the functions of the six modules of IHSDM.

2.3 Chapter Summary

In Chapter 2 a brief summary of the six modules of IHSDM and findings from the literature search were presented. Due to its short period of existence in the highway design related software market there is a lack of literature concerning the practical application of IHSDM. Of the six modules (PRM, CPM, DCM, TAM, IRM, and DVM) the scope of the study included only CPM and IRM because the objective of the study is to evaluate the applicability of IHSDM to safety audits of two-lane rural highways.

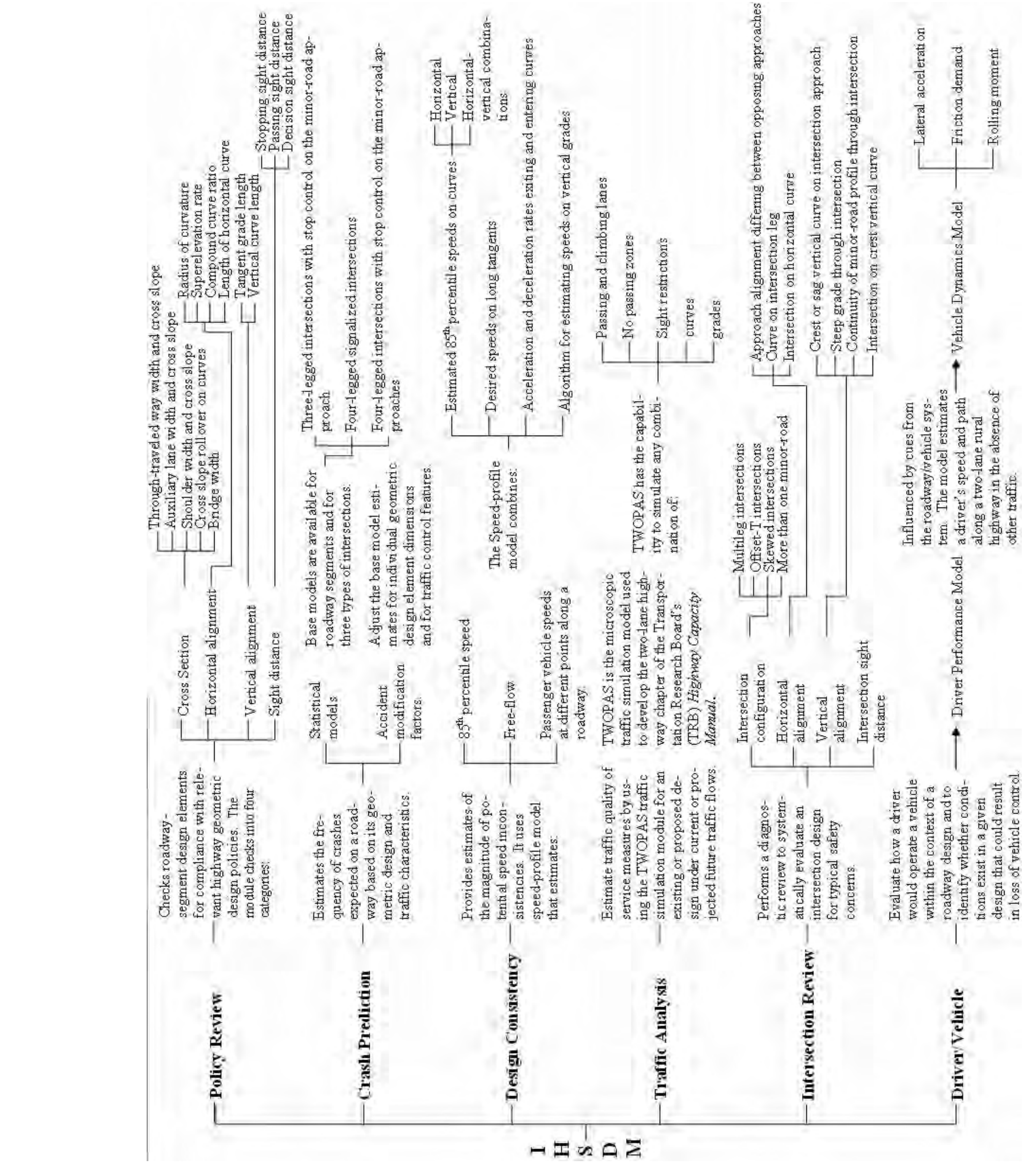


Figure 2-2: Summary Chart of IHSDM's Six Modules

3 Analysis Procedure

The study used the IHSDM 2006 version, which was the latest version available at the time the study began. The study focused on the evaluation of two modules of IHSDM: CPM and IRM. These two modules require horizontal and vertical alignments of the highway section under study. However, many two-lane rural highways in Utah were built more than 20 years ago and the original design and construction plans were unavailable. Furthermore, these two-lane rural highways have undergone repairs and reconstruction whose geometric design data were not available either. Therefore, in order to meet the data requirements of CPM and IRM, a new approach was used to obtain alignment data. This chapter discusses the procedure used to prepare necessary data for using the IHSDM.

Figure 3-1 displays the flowchart that outlines the analysis steps followed in this study. Highway sections were first chosen, and then the GPS data for each section were collected. The next step was to convert the GPS data into the format that were accepted by highway geometric design software. Then, surrogate centerline alignments for each study section were created. These alignment data were then entered into IHSDM. This chapter describes how these steps were carried out.

The analysis procedure presented in this report can be adopted for similar studies where crash prone segments within highway sections need to be identified and crash predictions are required for comparing improvement alternatives. Also, the method to produce surrogate horizontal and vertical alignments for two-way rural highways using GPS data will be useful for highway and safety engineers who desire to analyze the safety level of such highways but have not been able to do so because of the lack of design plans and/or as-built plans to extract horizontal and vertical alignments.

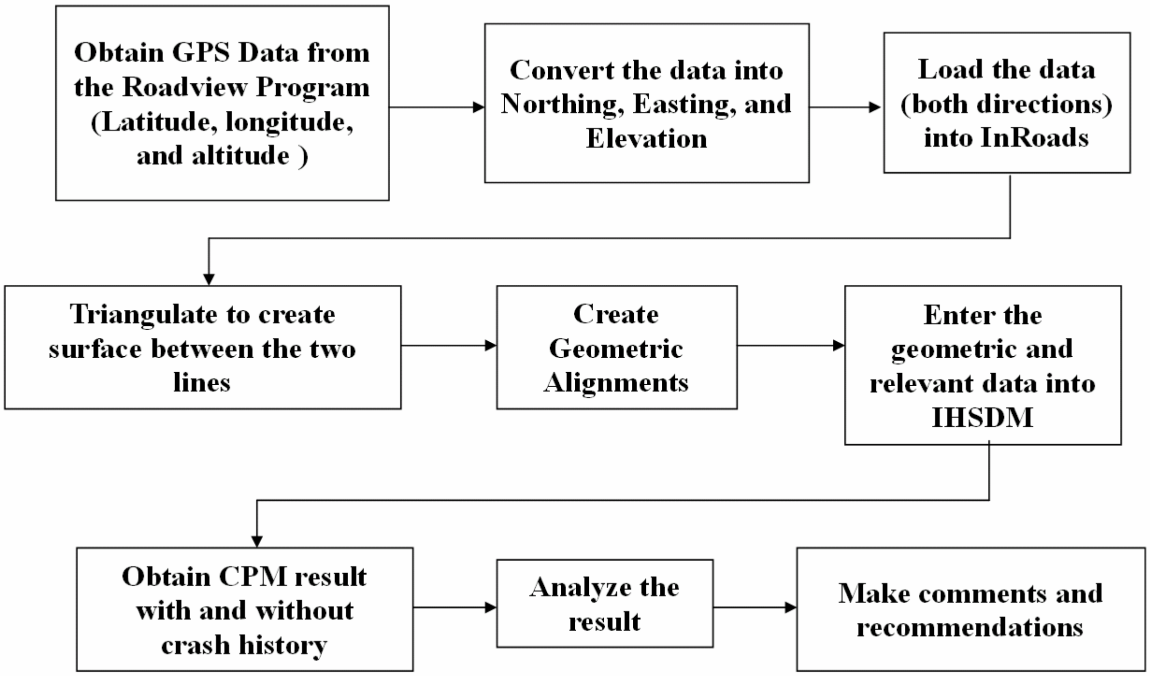


Figure 3-1: Flowchart of Analysis Steps

3.1 Data Collection

As mentioned in the introduction section of this chapter, IHSDM requires horizontal and vertical alignment data of the centerline of the highway section under study. Without these data no module of IHSDM runs. In order to compensate the lack of design plans and documents that might show alignment data a new approach for producing centerline alignments was needed. The research team found that UDOT had a photolog program for its highways and the images of the highways and GPS data of the data collection vehicle were available to public over the Internet, through the Roadview Explorer website (UDOT 2007a). The data provided by this website included milepost, latitude, longitude, altitude, and photo logs. Currently over half of the 50 states in the United States have adopted the method and constructed their own local route database (Mandli 2007).

Figure 3-2 shows an illustration of a photologging vehicle. The digital camera attached to the front windshield area of the vehicle has a resolution of 1600 pixels by 1200 pixels. It is positioned at the driver's eye height. From this position majority of travel lanes, street signs, guide signs, mile markers, pavement markings, and overhead signs can be captured by the camera. The camera has the capacity to take from100 up to 500 images per mile. A similar method was used for UDOT's photolog program.

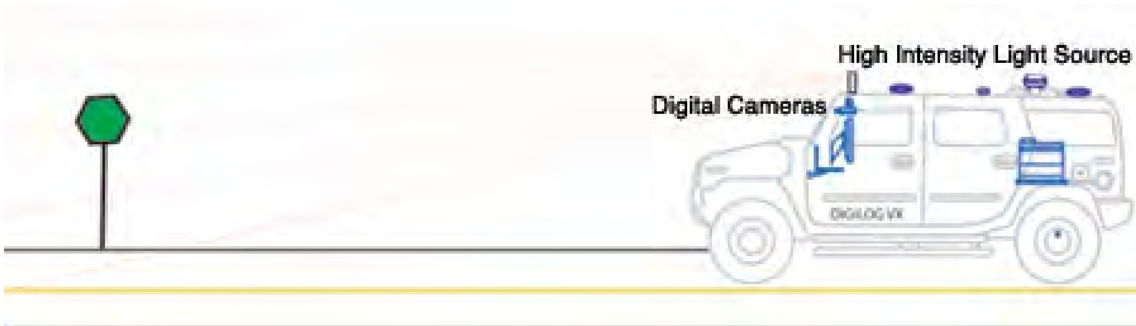


Figure 3-2: Illustration of a Data-Collecting Vehicle (Mandli 2007)

3.2 Obtaining Geometric Data

In this study, the GPS data of a selected highway section were used to create a surrogate centerline alignment for the selected highway section instead of its original road plans, which were basically non-existent. After the GPS data (longitude, latitude, and altitude) were obtained from the photolog program of UDOT, they were converted into coordinate data (northing, easting, and elevation) using the Watershed Modeling System (WMS) developed by Brigham Young University (BYU), and the converted coordinate data were then imported into InRoads to develop a surrogate centerline alignment. This particular procedure to obtain surrogate alignment data of two-lane rural highways was developed for this research and the procedure is discussed in detail in Appendix. (Note: This particular procedure was initially developed by Mike Mosley at BYU. The authors of this report modified the procedure as needed.)

3.3 Other Required Data for CPM

To run CPM several other types of data are required, including speed limit, Annual Average Daily Traffic (AADT), lane width, driveway density, cross slope, superelevation, crash history, etc. For some of these data, CPM uses default values if the user does not provide alternative values. In this particular study, the selected highways sections had their crash history available from 1992 to 2005 (UDOT 2006). However, considering that the road condition might have changed over such a long period of time, only the crash history from 2003 to 2005 was used. Also the AADT of corresponding years were obtained from UDOT (UDOT 2006). Likewise, for CPM, it would be unrealistic to expect a high accuracy in the output if the prediction period is too long. Hence, the prediction period was set to the same length of time, that is, three years from 2006 to 2008.

3.4 Entering Data into IHSDM

After all the required data are obtained, the next step is to enter or import these data into IHSDM. Among the types of required data that the user enters into IHSDM, entering alignment data is the one that would take the longest time if entered manually. To solve this problem, IHSDM provides several spreadsheets that were designed specifically to transform the raw alignment data into the format that is accepted by IHSDM. The spreadsheets can be accessed by selecting “Tools > Data Entry Assistant” in the main menu of IHSDM. Figure 3-3 shows how to locate the spreadsheets and Figure 3-4 shows the pop-up window after Data Entry Assistant is selected.

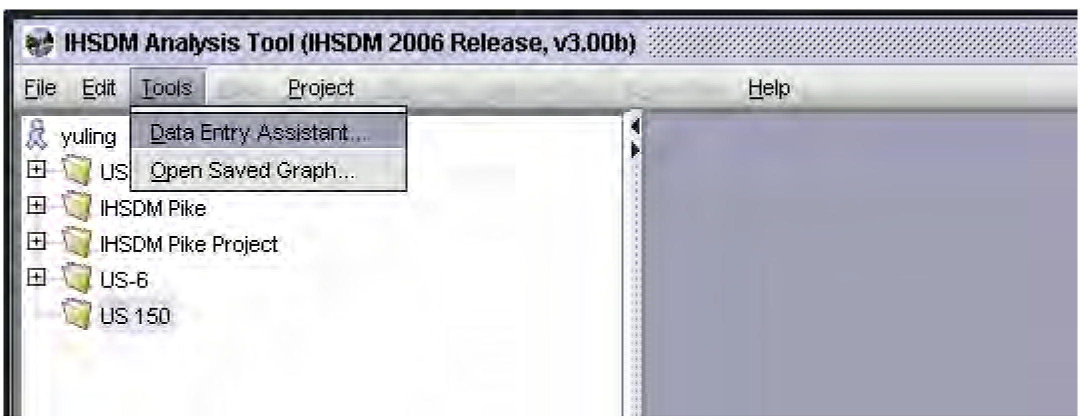


Figure 3-3: Screen Shot Showing the Location of the Geometric Alignment Assistant Spreadsheets

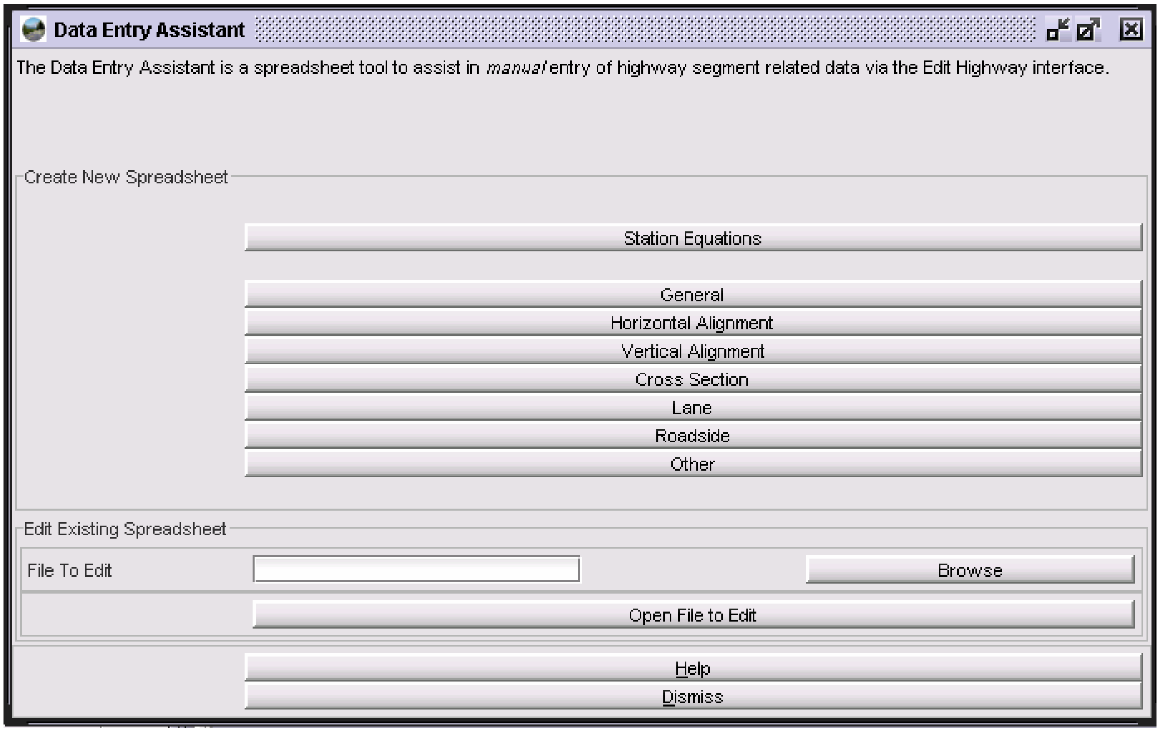


Figure 3-4: Data Entry Assistant Pop-Up Window

With the Data Entry Assistant the process of entering alignment data is greatly simplified. As to the rest of the data entry, the user only needs to use the Highway Editor, which is quite self-explanatory. A screenshot of the Highway Editor is shown in Figure 3-5. In the Highway Editor the user can switch between the different types of data by selecting appropriate tabs. The figure shows the window that contains several different tabs, labeled as General, Horizontal, Vertical, Cross Section, Lane, etc. Each tab gives the user data entry fields that are either required or optional. As mentioned previously, each module varies in its data requirements, and an easy way to tell which module uses certain types of data is to look at the lower left corner of the data entry area, where a statement in bold font states which modules use the particular data the user is entering. For example, in Figure 3-5 the text says "This element is used by PRM, CPM and IRM." This indicates that the daily traffic volume is used by the Policy Review Module, Crash Prediction Module, and Intersection Review Module. If there is any question about data entry, the Help button on the lower right has brief yet adequate explanations for the particular type of data shown on the current page.

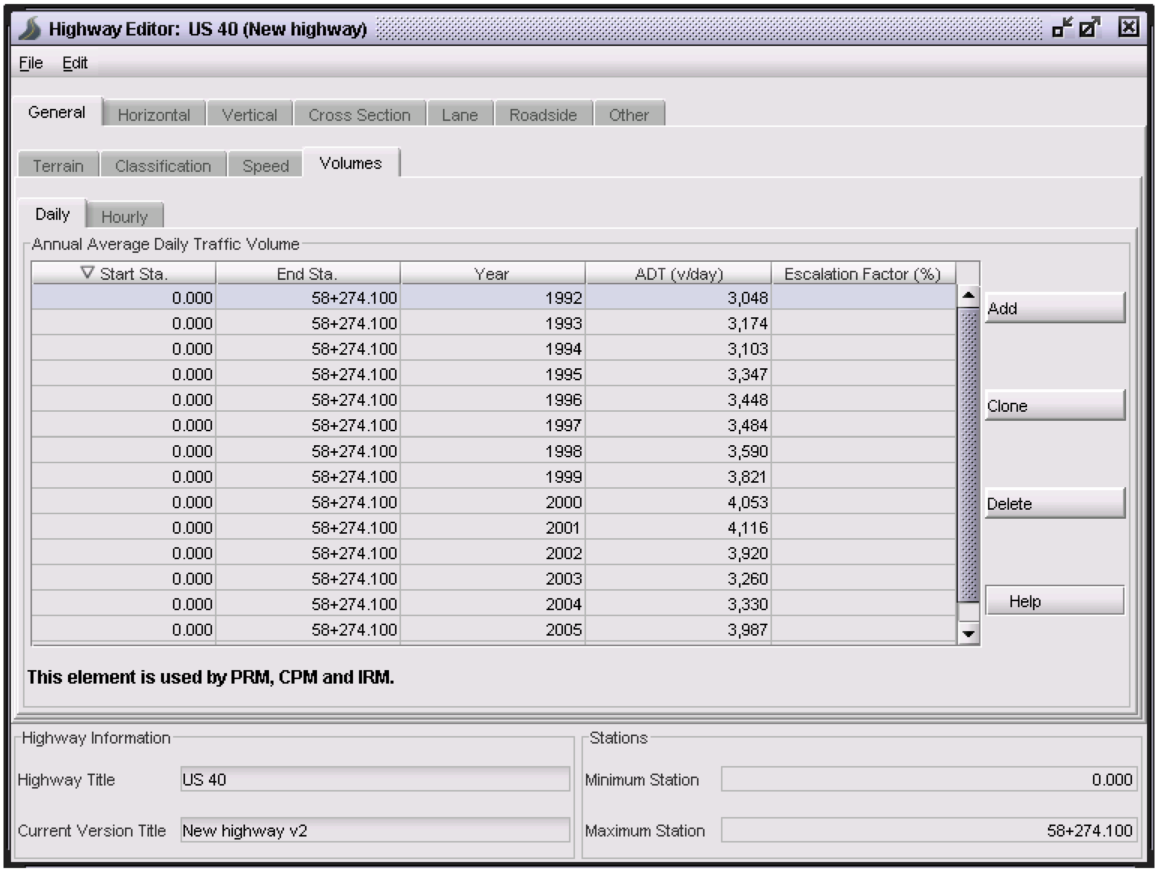


Figure 3-5: Screenshot of the Highway Editor of IHSDM

3.5 Chapter Summary

This chapter presented the procedure for preparing data to run the CPM and IRM module of IHSDM. To compensate the lack of the alignment data for two-lane rural highway a method that takes advantage of the already available UDOT's GPS data of two-lane rural highways was developed. GPS data were converted to the data format that could be read by InRoads and surrogate alignment data necessary for the two modules were created using the alignment creation features of InRoads. The surrogate alignments and other data were then entered into IHSDM to run the CPM or IRM modules.

4 Application of CPM to Selected Highway Sections

Three sections of two-lane rural highways in Utah were selected for analysis. To make the selections, the traffic and safety engineers of UDOT's four regions, who were members of the TAC of the study, were asked to provide their preference on specific highway sections that have experienced a high number of crushes. From their lists of potential study sites three sections shown in Table 4-1 were selected. There was no appropriate study section available in Region 1.

Table 4-1: Three Highway Sections Selected for Analysis

Highway	Milepost	Region
US-40	From MP35 to MP45	3
US-6	From MP22 to MP28	4
SR-150	From MP0.6 to MP16.4	2

The three study sections selected for analysis were all two-lane rural highways, which were the target study type of roads for IHSDM. Also, they were all of reasonable length, and most importantly, the three study sections were listed as one of the most crash prone highway sections on their lists.

In using the prediction models of the CPM, no adjustment was made for the calibration factor which can be used to adjust the model to the local conditions for two reasons: 1) it was desired to test if the CPM could be used as is, and 2) the calibration task was, therefore, outside the scope of this study. It is advantageous if the calibration task could be eliminated.

Figure 4-1 shows the general locations of the three selected highway sections on a Utah highway map (UDOT 2008). As shown in the figure the three study sections are located on the northern and middle part of the state.

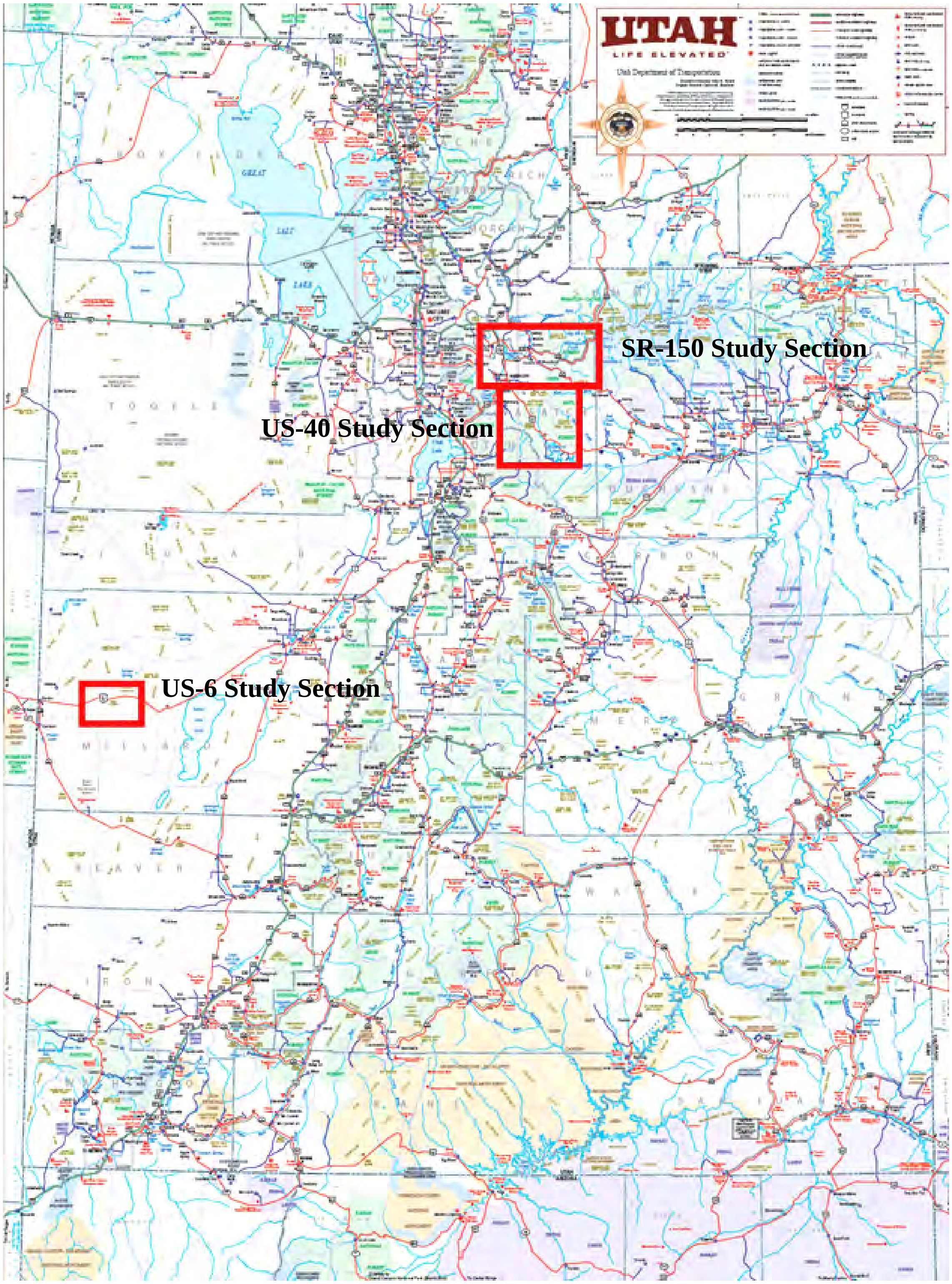


Figure 4-1: Locations of the Three Selected Two-Lane Rural Highway Sections (UDOT 2008)

4.1 US-40 Study Section

Located in UDOT Region 3, the US-40 Study Section, from MP 35 to MP 45, was selected for its undesirable crash history. This particular section became an ideal section for the study for its length and its proximity to BYU, where the authors worked.

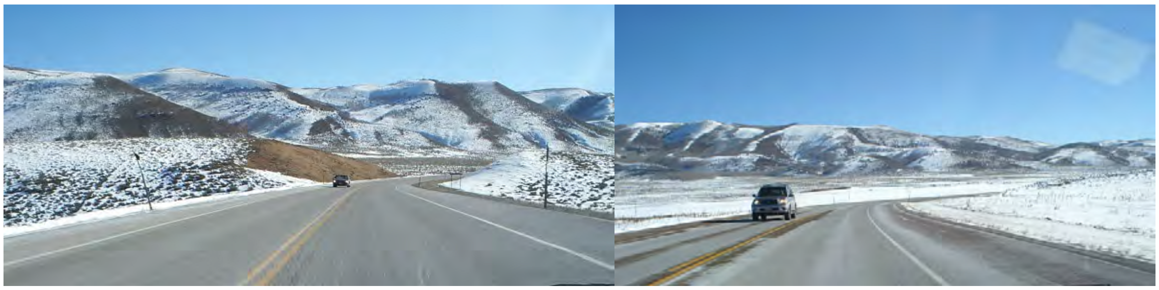
4.1.1 Current Conditions of the US-40 Study Section

A field visit was made to the study section. The general conditions of the study section were found to be good. The pavement was in acceptable condition, the lane markings were clearly visible, and the traffic signs appeared to be properly installed and properly functioning.

Figure 4-2 and Figure 4-3 are the photos taken of the US-40 study section during two different seasons. They are shown to help the readers understand the general setting of this study section. Figure 4-4 shows the location of the US-40 study section from MP 35 to MP 45. The surrogate centerline horizontal alignment of the study section shown in Figure 4-5 was created by InRoads using the GPS data supplied by UDOT's photolog specialists. As shown in Figure 4-4 and Figure 4-5, the surrogate centerline alignment appears practically identical to the highway section shown in Figure 4-4.

(a) MP37, Eastbound (b) MP38, Westbound

Figure 4-2: Photos of the US-40 Study Section in Summer 2005 (UDOT 2007a)



(a) MP38, Westbound (b) MP37, Eastbound

Figure 4-3: Photos of the US-40 Study Section in Winter 2006 (UDOT 2008) (Taken by Kaitlin Chuo)

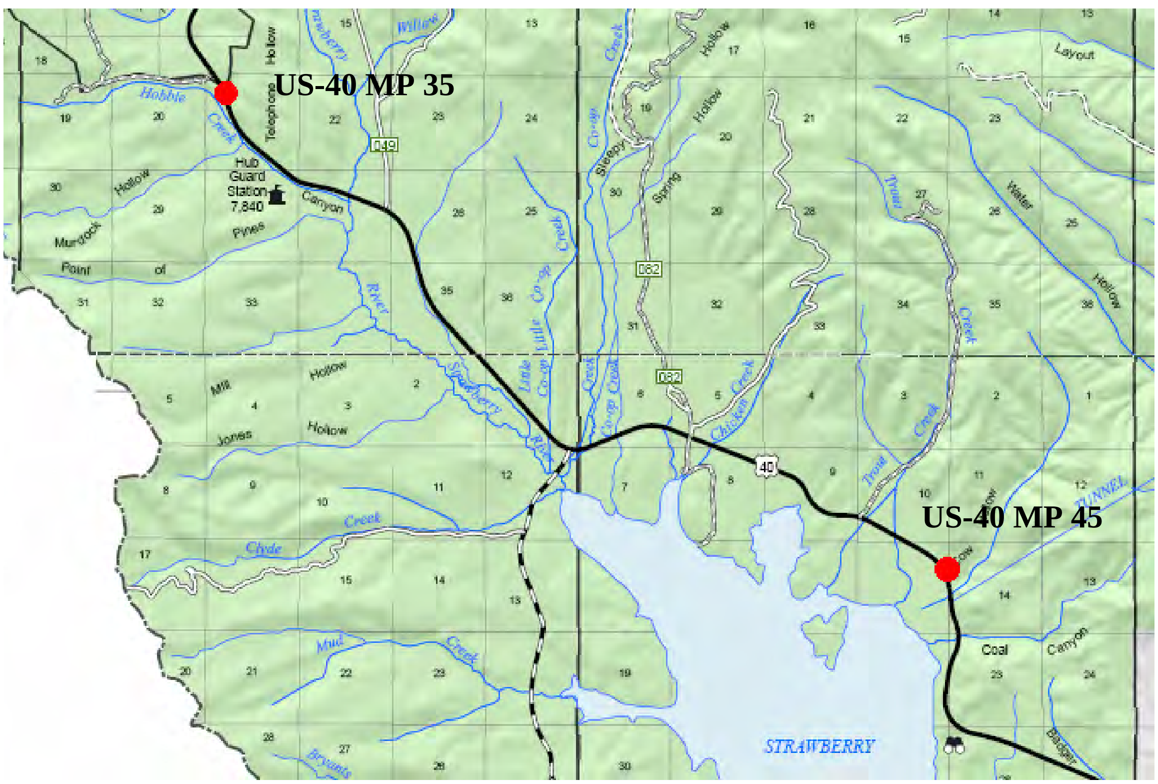


Figure 4-4: Location of the US-40 Study Section (UDOT 2008)

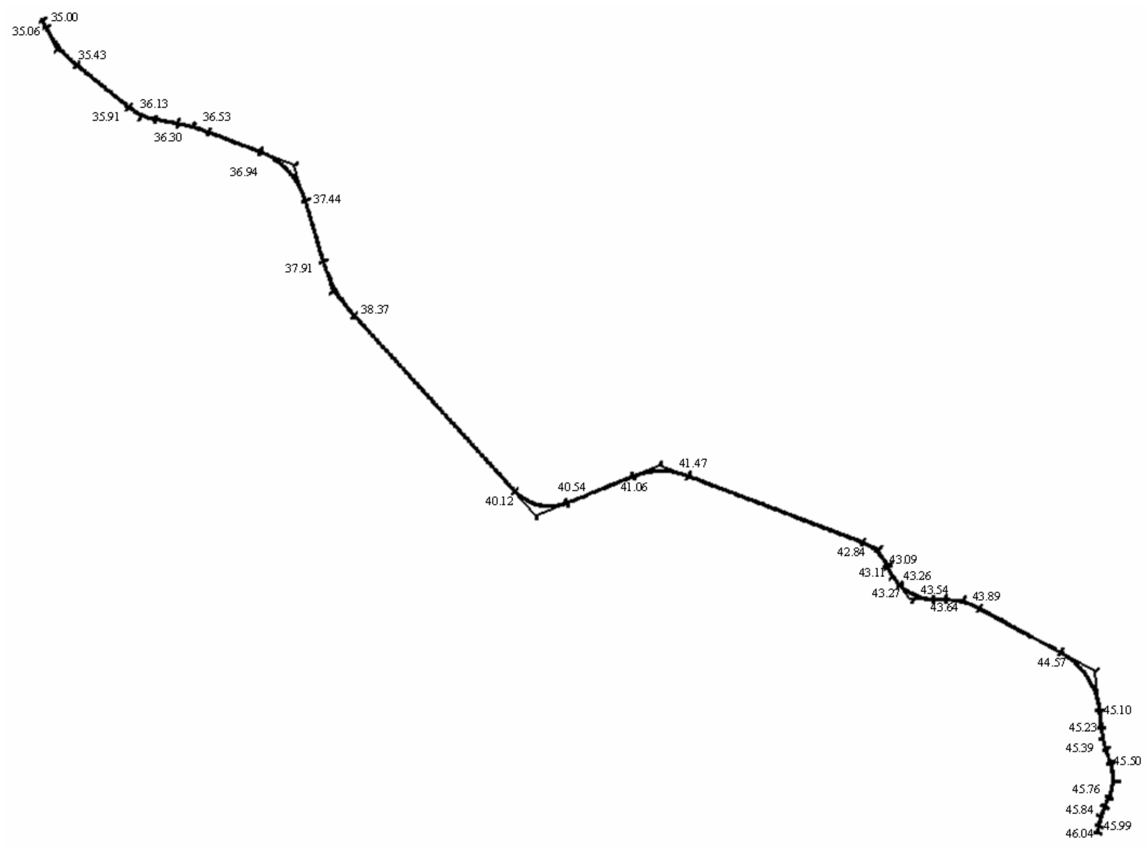


Figure 4-5: Surrogate Horizontal Alignment of the US-40 Study Section with Mileposts

4.1.2 Centerline Alignments of the US-40 Study section

As mentioned previously, GPS data (longitude, latitude, and altitude) were obtained from UDOT's photolog specialists and converted into appropriate data (northing, easting, and elevation) to import into InRoads. The centerline horizontal and vertical alignments were then manually created in InRoads (see Appendix for the details of creating surrogate alignments). When creating surrogate alignments, it is important to keep them closely follow the geometry, yet also stay at reasonable details instead of excessively trying to match all the details, which may waste time.

The resulting horizontal and vertical alignments are presented in Table 4-2 and Table 4-3.

Table 4-2: The Horizontal Alignment of the US-40 Study Section (MP 35 to MP 45)

Segment	Milepost		Radius
	From	To	
Tangent	35.00	35.06	---
Simple Curve	35.06	35.43	4500
Tangent	35.43	35.91	---
Simple Curve	35.91	36.13	2300
Tangent	36.13	36.30	---
Simple Curve	36.30	36.53	7000
Tangent	36.53	36.94	---
Simple Curve	36.94	37.44	2900
Tangent	37.44	37.91	---
Simple Curve	37.91	38.37	5500
Tangent	38.37	40.12	---
Simple Curve	40.12	40.54	1800
Tangent	40.54	41.06	---
Simple Curve	41.06	41.47	2900
Tangent	41.47	42.84	---
Simple Curve	42.84	43.09	1700
Tangent	43.09	43.11	---
Simple Curve	43.11	43.26	2500
Tangent	43.26	43.27	---
Simple Curve	43.27	43.54	1800
Tangent	43.54	43.64	---
Simple Curve	43.64	43.89	2775
Tangent	43.89	44.57	---
Simple Curve	44.57	45.10	2950
Tangent	45.10	45.23	---
Simple Curve	45.23	45.39	4500
Tangent	45.39	45.50	---
Simple Curve	45.50	45.50	5000
Tangent	45.50	45.50	---
Simple Curve	45.50	45.76	1930
Tangent	45.76	45.84	---
Simple Curve	45.84	45.99	3500
Tangent	45.99	46.04	---

Table 4-3: Vertical Alignment of the US-40 Study Section (MP 35 to MP 45)

Milepost	Back Grade (%)	Back Length (ft)	Forward Grade (%)	Forward Length (ft)
35.21	-4.08	600	-1.20	600
35.89	-1.20	250	-1.45	250
36.17	-1.45	500	-0.95	500
36.61	-0.95	500	0.15	500
37.19	0.15	500	-1.57	500
38.02	-1.57	1250	-0.55	1250
39.29	-0.55	500	-0.70	500
39.99	-0.70	1500	0.51	1500
41.11	0.51	500	-0.72	500
41.41	-0.72	500	0.69	500
41.98	0.69	1625	-0.61	1625
42.90	-0.61	800	3.48	800
43.41	3.48	875	-2.64	875
43.75	-2.64	600	-0.28	600
44.13	-0.28	750	-1.78	750
44.62	-1.78	600	0.35	600
45.51	0.35	500	-0.35	500

4.1.3 Crash Prediction Results of the US-40 Study Section

The purpose of this study was to evaluate the capability of CPM for identifying "hot spots" in a safety audit where crash rates would be higher than other parts of the section. In order to evaluate the sensitivity of CPM results two alternative tests were made: one evaluated with crash history and the other without crash history. The comparison of their results can be made to check if CPM is capable of making appropriate crash predictions independently without crash history. This capability becomes important when the effectiveness of multiple improvement alternatives is tested in terms of crash reduction. In comparing multiple improvement alternatives crash histories of such alternatives are not available. Hence, being able to produce crash predictions along the highway section without crash history is important. To ensure the accuracy and reliability of the prediction results, only the crash data from 2003 to 2005 were used and the three year prediction was made. Table 4-4 presents the prediction results in number of crashes for the US-40 study section from MP 35 to MP 45.

Figure 4-6, Figure 4-7 and Figure 4-8 are graphical presentations of the crash prediction results shown in Table 4-4, prepared to help the readers visually compare the difference in the number of crashes along the centerline alignments of the study section, while Figure 4-9shows the differences between the CPM results analyzed with and without crash history.

Table 4-4: Crash Prediction Results for the US-40 Study section (Number of Crashes)

Milepost		No. of Crashes (2006-2008)			No. of Crashes (2003-2005)
From	To	with Crashes	w/o Crashes	Diff.	Crash History
35.00	35.06	0.55	0.182	0.37	1.00
35.06	35.43	2.65	1.26	1.39	4.00
35.43	35.91	2.18	1.40	0.77	3.00
35.91	36.13	0.97	0.83	0.15	1.00
36.13	36.30	0.73	0.48	0.25	1.00
36.30	36.53	1.36	0.74	0.62	2.00
36.53	36.94	1.15	1.15	0.00	1.00
36.94	37.44	3.43	1.74	1.68	5.00
37.44	37.91	1.72	1.36	0.36	2.00
37.91	38.37	1.81	1.48	0.33	2.00
38.37	40.12	6.56	4.98	1.58	8.00
40.12	40.54	2.89	1.55	1.34	4.00
40.54	41.06	1.36	1.48	0.12	1.00
41.06	41.47	2.29	1.44	0.85	3.00
41.47	42.84	5.03	3.90	1.13	6.00
42.84	43.09	1.62	1.02	0.60	2.00
43.09	43.11	0.06	0.06	0.02	0.00
43.11	43.26	0.34	0.62	0.28	0.00
43.26	43.27	0.01	0.02	0.01	0.00
43.27	43.54	1.65	1.10	0.55	2.00
43.54	43.64	0.17	0.27	0.10	0.00
43.64	43.89	2.00	0.93	1.07	3.00
43.89	44.57	1.66	1.94	0.29	1.00
44.57	45.10	2.51	1.84	0.68	3.00
45.10	45.23	0.23	0.37	0.14	0.00
35.00	35.06	0.55	0.182	0.37	1.00

Table 4-4: Crash Prediction Results for the US-40 Study section (Number of Crashes) (continued)

Milepost		No. of Crashes (2006-2008)			No. of Crashes (2003-2005)
From	**To**	**with Crashes**	**w/o Crashes**	**Diff.**	**Crash History**
35.06	35.43	2.65	1.26	1.39	4.00
35.43	35.91	2.18	1.40	0.77	3.00
35.91	36.13	0.97	0.83	0.15	1.00
36.13	36.30	0.73	0.48	0.25	1.00
36.30	36.53	1.36	0.74	0.62	2.00
36.53	36.94	1.15	1.15	0.00	1.00
36.94	37.44	3.43	1.74	1.68	5.00
37.44	37.91	1.72	1.36	0.36	2.00
37.91	38.37	1.81	1.48	0.33	2.00
38.37	40.12	6.56	4.98	1.58	8.00
40.12	40.54	2.89	1.55	1.34	4.00
40.54	41.06	1.36	1.48	0.12	1.00
41.06	41.47	2.29	1.44	0.85	3.00
41.47	42.84	5.03	3.90	1.13	6.00
42.84	43.09	1.62	1.02	0.60	2.00
43.09	43.11	0.06	0.06	0.02	0.00
43.11	43.26	0.34	0.62	0.28	0.00
43.26	43.27	0.01	0.02	0.01	0.00
43.27	43.54	1.65	1.10	0.55	2.00
43.54	43.64	0.17	0.27	0.10	0.00
43.64	43.89	2.00	0.93	1.07	3.00
43.89	44.57	1.66	1.94	0.29	1.00
44.57	45.10	2.51	1.84	0.68	3.00
45.10	45.23	0.23	0.37	0.14	0.00
45.23	45.39	0.32	0.54	0.22	0.00
45.39	45.50	0.19	0.30	0.11	0.00
45.50	45.50	0.01	0.02	0.01	0.00
45.50	45.50	0.00	0.00	0.00	0.00
45.50	45.76	0.56	0.10	0.44	0.00
45.76	45.84	0.13	0.21	0.08	0.00
45.84	45.99	0.31	0.54	0.23	0.00
45.99	46.04	0.09	0.14	0.05	0.00

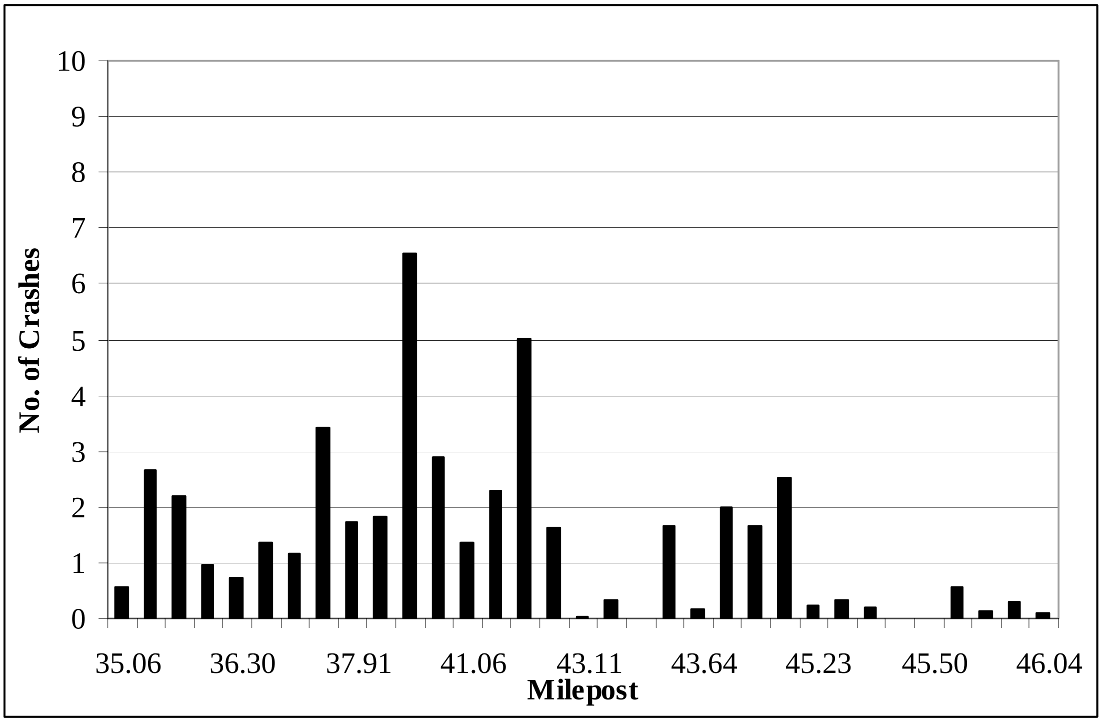


Figure 4-6: Plot of CPM Prediction Results of the US-40 Study Section (Number of Crashes), MP 35-MP 45 (2006-2008), Analyzed with Crash History

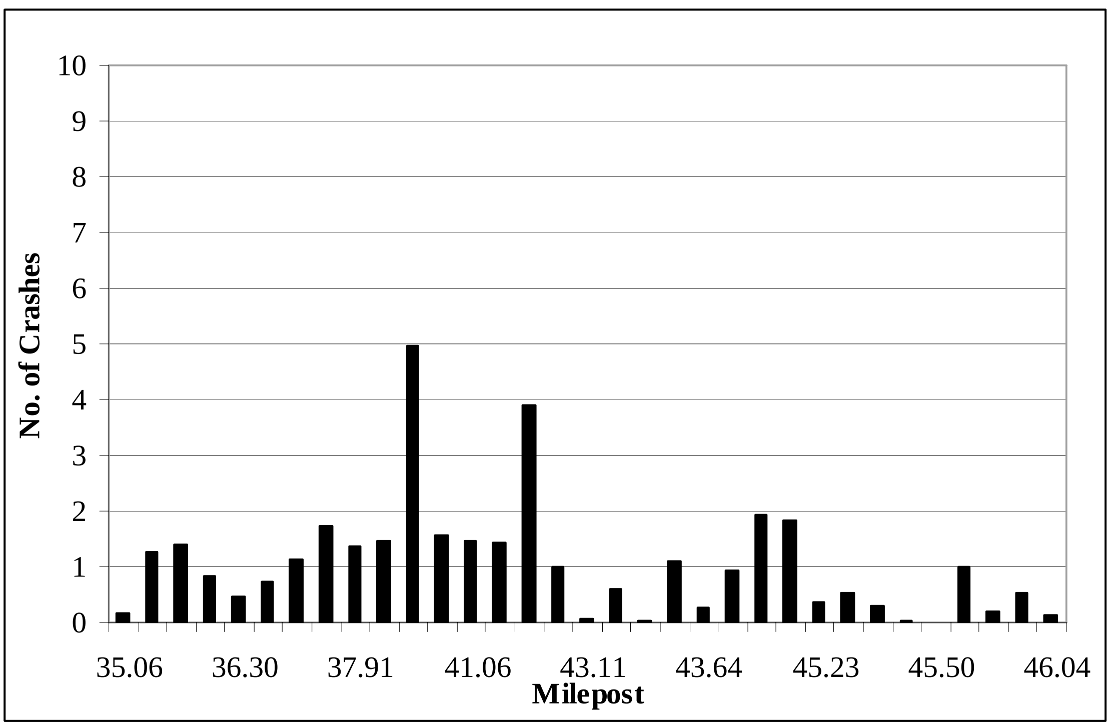


Figure 4-7: Plot of CPM Prediction Results of US-40 Study Section (Number of Crashes), MP 35-MP 45 (2006-2008), Analyzed without Crash History

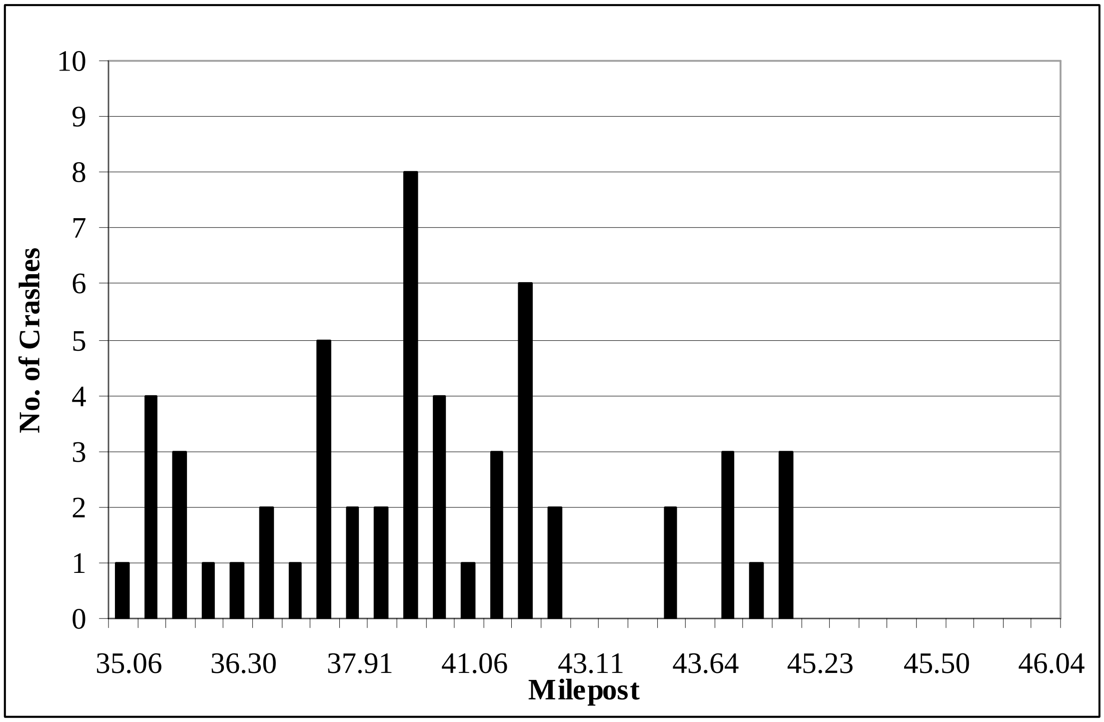


Figure 4-8: Plot of Crash History of US-40 Study Section (Number of Crashes), MP 35-MP 45 (2003-2005)

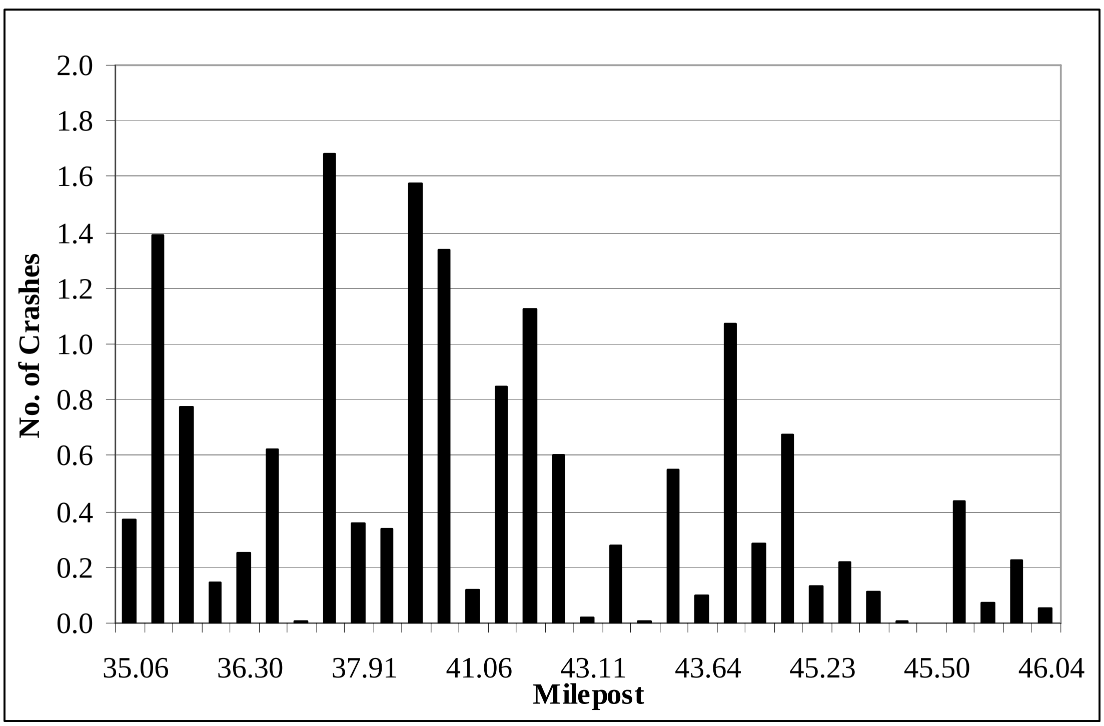


Figure 4-9: Plot of the Difference Between the CPM Results of US-40 Study Section in Number of Crashes Analyzed With and Without Crash History

Figure 4-6 and Figure 4-7 show that the two prediction results from CPM have trends similar to Figure 4-8, the actual crash history. All three plots show high peaks around MP 35.7, MP 37.1, MP 42.6, and MP 44.4, with the highest peak at MP 40.3. There is one thing worth noticing: Figure 4-7, which shows the crash prediction results without crash history exhibits a trend similar to the ones in Figure 4-6 and Figure 4-7. Figure 4-9 was created to show the difference in number of crashes between the CPM results with and without crash history. Table 4-5 shows a summary of statistics of the differences shown in Figure 4-9. It shows that the mean difference in the number of crashes between the two methods is less than 0.5, and the standard error of the mean is very small (0.085), resulting in the confidence interval of 0.312 and 0.646 at the 95 percent confidence level. From the statistics presented in Table 4-5 it can be said that the crash prediction without crash history is able to produce crash predictions that are similar to the crash prediction with crash history.

Table 4-5: Statistical Summary of the Difference between the CPM Results in Number of Crashes Analyzed With and Without Crash History of US-40 Study Section

Mean	0.479
Standard Error	0.085
Median	0.285
Standard Deviation	0.490
Sample Variance	0.240
Kurtosis	0.304
Skewness	1.151
Range	1.683
Minimum	0.002
Maximum	1.684
Confidence Interval of the Mean (at the 95% Confidence Level)	0.312 – 0.646

Now that the similarity between the CPM results with and without crash history in number of crashes was found, crash rates per MVMT were compared for the with and without crash history cases. From equation 2--2 it is evident that the computation of number of crashes considers the exposure aspect of crashes. Hence, looking at the crashes per MVMT is basically removing this exposure effect. Segments in the study section are defined as elements of horizontal alignment such as tangent or curve segment of the horizontal alignment. The computed crash rates are presented in Table 4-6 and Figure 4-10, Figure 4-11, and Figure 4-12 were prepared to visualize the trends in the prediction results. And the differences between the two CPM results were shown in Table 4-6 and plotted in Figure 4-13.

Table 4-6: Crash Prediction Results for the US-40 Study Section (Crashes/MVMT)

Milepost		Length (mi)	Expected Crash Rate (2006-2008) (MVMT)			Crash Rate (2003-2005) (MVMT)
From	To		with Crashes	w/o Crashes	Diff.	Crash History
35.00	35.06	0.06	2.06	0.68	1.38	3.99
35.06	35.43	0.37	1.61	0.77	0.84	2.61
35.43	35.91	0.48	1.01	0.65	0.36	1.50
35.91	36.13	0.22	1.02	0.86	0.16	1.12
36.13	36.30	0.17	0.98	0.65	0.33	1.44
36.30	36.53	0.23	1.31	0.71	0.60	0.00
36.53	36.94	0.41	0.64	0.64	0.00	0.59
36.94	37.44	0.50	1.53	0.78	0.75	2.40
37.44	37.91	0.47	0.82	0.65	0.17	1.03
37.91	38.37	0.47	0.88	0.71	0.17	1.04
38.37	40.12	1.75	0.84	0.64	0.20	1.10
40.12	40.54	0.42	1.56	0.84	0.72	2.32
40.54	41.06	0.52	0.59	0.64	0.05	0.46
41.06	41.47	0.41	1.25	0.78	0.47	1.75
41.47	42.84	1.37	0.83	0.64	0.19	1.05
42.84	43.09	0.25	1.46	0.92	0.54	1.94
43.09	43.11	0.02	0.42	0.67	0.25	0.00
43.11	43.26	0.15	0.50	0.91	0.41	0.00
43.26	43.27	0.01	0.42	0.67	0.25	0.00
43.27	43.54	0.27	1.36	0.91	0.45	1.76
43.54	43.64	0.09	0.41	0.66	0.25	0.00
43.64	43.89	0.25	1.76	0.82	0.94	2.83

Table 4-6: Crash Prediction Results for the US-40 Study Section (Crashes/MVMT) (continued)

Milepost		Length (mi)	Expected Crash Rate (2006-2008) (MVMT)			Crash Rate (2003-2005) (MVMT)
From	To		with Crashes	w/o Crashes	Diff.	Crash History
43.89	44.57	0.68	0.55	0.65	0.10	0.36
44.57	45.10	0.53	1.06	0.77	0.29	1.35
45.10	45.23	0.13	0.40	0.64	0.24	0.00
45.23	45.39	0.16	0.45	0.76	0.31	0.00
45.39	45.50	0.11	0.40	0.64	0.24	0.00
45.50	45.50	0.00	0.55	1.09	0.54	0.00
45.50	45.50	0.00	0.40	0.64	0.24	0.00
45.50	45.76	0.26	0.48	0.86	0.38	0.00
45.76	45.84	0.07	0.40	0.64	0.24	0.00
45.84	45.99	0.15	0.47	0.80	0.33	0.00
45.99	46.04	0.05	0.40	0.64	0.24	0.00

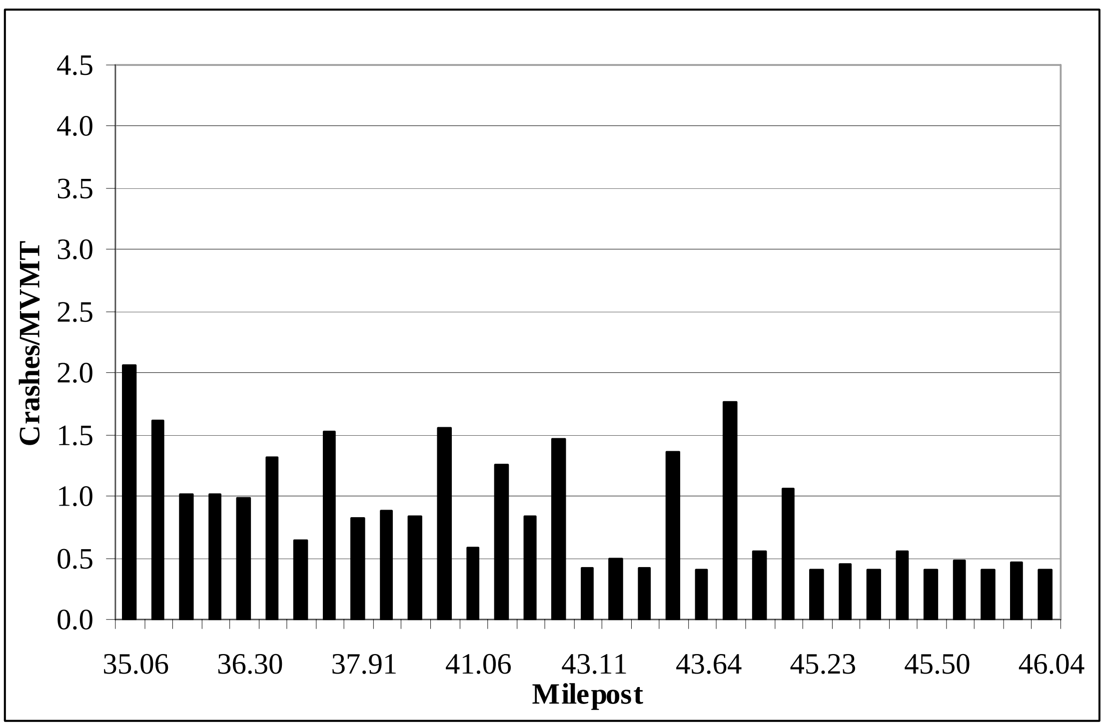


Figure 4-10: Plot of CPM Prediction Results of the US-40 Study Section (Crashes/MVMT), MP 35-MP 45 (2006-2008), Analyzed with Crash History

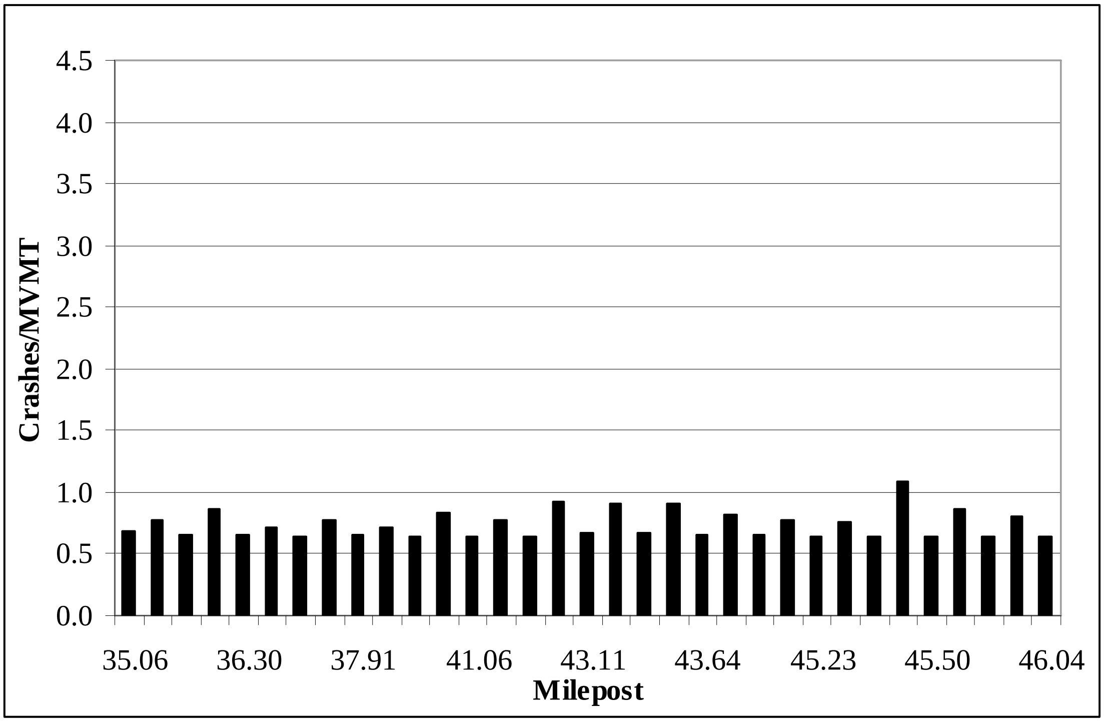


Figure 4-11: Plot of CPM Prediction Results of the US-40 Study Section (Crashes/MVMT), MP 35-MP 45 (2006-2008), Analyzed without Crash History

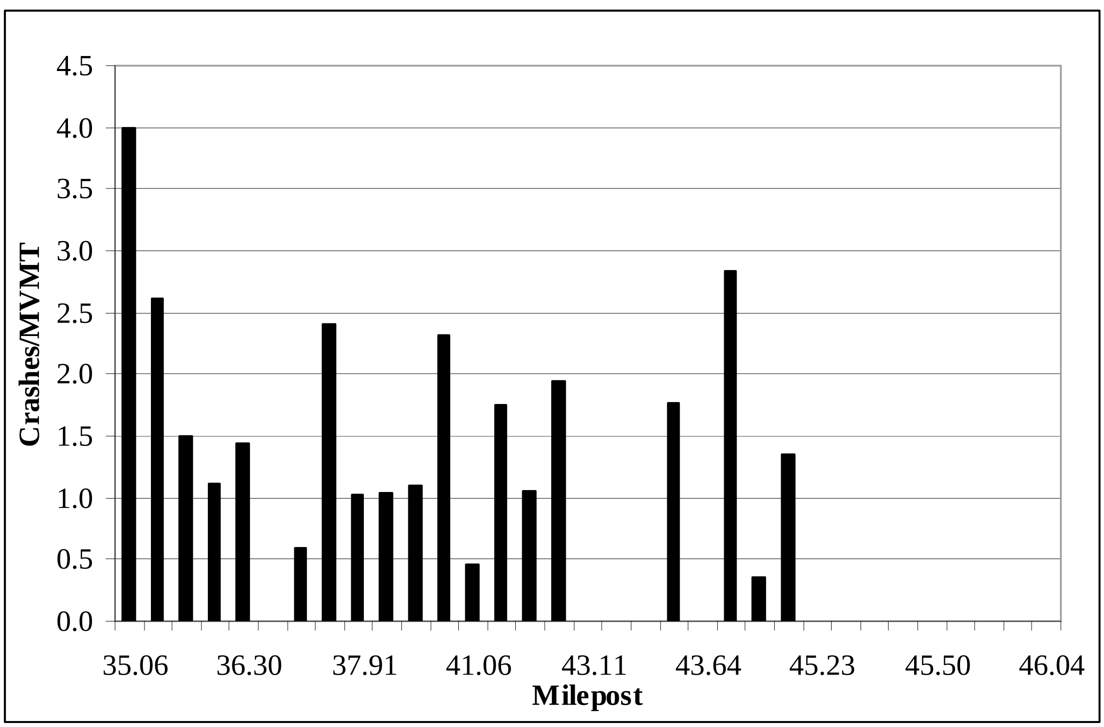


Figure 4-12: Plot of Crash History of US-40 Study Section (Crashes/MVMT), MP 35-MP 45 (2003-2005)

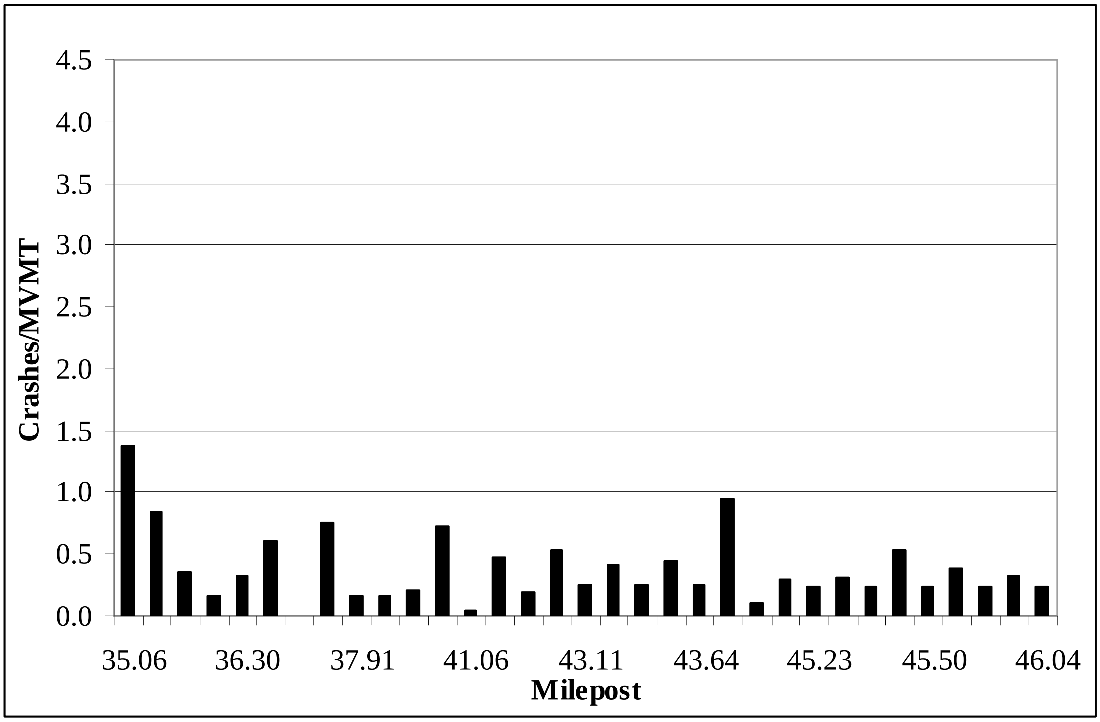


Figure 4-13: Plot of the Difference Between the CPM Results of US-40 Study Section in Crashes/MVMT Analyzed With and Without Crash History

A summary of statistics of the difference between the CPM results analyzed with and without crash history in crashes/MVMT is shown in Table 4-7. It shows that the mean difference in the number of crashes per MVMT between the two methods is less than 0.5, and the standard error of the mean is very small (0.050), resulting in the confidence interval of 0.285 and 0.481 at the 95% confidence level. Compared with the number of crashes, the relative difference in the number of crashes per MVMT between the prediction with and without crash history resulted larger the number of crashes per segment.

Table 4-7: Statistics Summary of the Difference between the CPM Results in Crashes/MVMT Analyzed With and Without Crash History of US-40 Study Section

Mean	0.383
Standard Error	0.050
Median	0.290
Standard Deviation	0.285
Sample Variance	0.081

Table 4-7: Statistics Summary of the Difference between the CPM Results in Crashes/MVMT Analyzed With and Without Crash History of US-40 Study Section (continued)

Kurtosis	3.670
Skewness	1.708
Range	1.380
Minimum	0.000
Maximum	1.380
Confidence Interval of the Mean (at the 95% Confidence Level)	0.285 – 0.481

4.1.4 Analysis of Crash Prediction Results of the US-40 Study Section

Before analyzing the crash prediction results, one thing needs to be kept in mind, that is, it is unrealistic to expect the CPM to have the capacity to predict the exact number of crashes in the future. The users must use the results to read a general trend in the output and determine the locations where a high number of crashes are likely to occur, instead of using the particular numbers of crashes presented by the CPM as "real" number of crashes that may occur.

Figure 4-6 and Figure 4-7, which show the number of crashes per segment, display similar trends but Figure 4-10 and Figure 4-11, which show the number of crashes per MVMT appear distinct to each other. Though the mean difference was small (less than 0.5 crashes), the relative amount of the mean difference is larger for the latter case. In the latter case, segments with similar crash rates per MVMT had similar physical characteristics; for instance, tangent segments have similar numbers of crashes per MVMT.

Based on the given prediction results and the crash history, two different interpretations can be made: either the CPM is not yet reliable to be used for this type of analysis, or the crash history of the US-40 study section is different from the ones used for the development of CPM. This finding prompted an in-depth analysis of the crash history used for the analysis before making any judgment.

Table 4-8 shows the detailed crash history data of the US-40 study section. It turned out that 60 percent of the crashes on the US-40 study section were caused by collisions with wild animals. This could become a potential problem because this factor is not fundamentally controlled by the engineering aspects of highway design. Surely, there can be a way to herd domestic animals to certain highway crossing points, but it is difficult to guide wild animals to certain crossing points. Figure 4-14 shows where crashes with wild animals took place in the three year crash analysis period. As seen in the figure, they are scattered throughout the study section.

Table 4-8: Crash History Summary of the US-40 Study Section, MP 35-MP 45 (2003-2005)

Year	Direction	Milepost	Severity	Accident Type 1	Accident Type 2	Accident Type 3
2003	E	35.17	No Injury	MV-Animal(Wild)	NULL	NULL
2003	E	35.27	No Injury	MV-Animal(Wild)	NULL	NULL
2003	E	36.18	Bruises And Abrasions	Ran Off Roadway-Right	MV-Fixed Object	NULL
2003	E	36.49	No Injury	MV-Animal(Wild)	NULL	NULL
2003	E	36.76	No Injury	MV-Animal(Wild)	NULL	NULL
2003	E	38.05	No Injury	Ran Off Roadway-Left	Overturned	NULL
2003	W	38.75	No Injury	MV-Animal(Wild)	NULL	NULL
2003	E	39.25	No Injury	Ran Off Roadway-Right	MV-Fixed Object	NULL
2003	W	39.54	No Injury	MV-Animal(Wild)	NULL	NULL
2003	E	40.73	No Injury	MV-Animal(Wild)	NULL	NULL
2003	W	41.13	No Injury	MV-Fixed Object	Ran Off Roadway-Right	NULL
2003	W	41.86	No Injury	MV-Animal(Wild)	NULL	NULL
2003	E	35.17	No Injury	MV-Animal(Wild)	NULL	NULL
2003	E	35.27	No Injury	MV-Animal(Wild)	NULL	NULL
2003	E	36.18	Bruises And Abrasions	Ran Off Roadway-Right	MV-Fixed Object	NULL

Table 4-8: Crash History Summary of the US-40 Study Section, MP 35-MP 45 (2003-2005) (continued)

Year	Direction	Milepost	Severity	Accident Type 1	Accident Type 2	Accident Type 3
2003	E	36.49	No Injury	MV-Animal(Wild)	NULL	NULL
2003	E	36.76	No Injury	MV-Animal(Wild)	NULL	NULL
2003	E	38.05	No Injury	Ran Off Roadway-Left	Overturned	NULL
2003	W	38.75	No Injury	MV-Animal(Wild)	NULL	NULL
2003	E	39.25	No Injury	Ran Off Roadway-Right	MV-Fixed Object	NULL
2003	W	39.54	No Injury	MV-Animal(Wild)	NULL	NULL
2003	E	40.73	No Injury	MV-Animal(Wild)	NULL	NULL
2003	W	41.13	No Injury	MV-Fixed Object	Ran Off Roadway-Right	NULL
2003	W	41.86	No Injury	MV-Animal(Wild)	NULL	NULL
2003	W	42.06	No Injury	Ran Off Roadway-Right	MV-Fixed Object	Ran Off Roadway-Left
2003	W	44.55	No Injury	MV-Animal(Wild)	NULL	NULL
2003	W	44.75	No Injury	MV-Animal(Wild)	NULL	NULL
2004	W	35.07	Bruises And Abrasions	Ran Off Roadway-Left	Overturned	NULL
2004	E	35.27	No Injury	Overturned	NULL	NULL
2004	W	35.67	No Injury	Ran Off Roadway-Right	MV-Other Object	Overturned
2004	E	35.68	Fatal	MV-MV	NULL	NULL
2004	E	35.76	No Injury	MV-Animal(Wild)	NULL	NULL
2004	W	36.45	No Injury	Other Non-Collision	MV-Other Object	NULL

Table 4-8: Crash History Summary of the US-40 Study Section, MP 35-MP 45 (2003-2005) (continued)

Year	Direction	Milepost	Severity	Accident Type 1	Accident Type 2	Accident Type 3
2004	E	37.01	Bruises And Abrasions	Ran Off Roadway-Right	Ran Off Roadway-Left	NULL
2004	E	37.36	No Injury	MV-Animal(Wild)	NULL	NULL
2004	E	37.95	Broken bones or bleeding wounds	MV-Animal(Wild)	Ran Off Roadway-Right	Overturned
2004	W	38.85	No Injury	MV-Animal(Wild)	NULL	NULL
2004	E	38.95	No Injury	MV-Animal(Wild)	MV-MV	MV-MV
2004	E	39.24	No Injury	MV-Animal(Wild)	NULL	NULL
2004	W	40.03	No Injury	MV-Animal(Wild)	NULL	NULL
2004	N	40.34	No Injury	MV-MV	Ran Off Roadway-Right	MV-Fixed Object
2004	W	40.44	No Injury	Ran Off Roadway-Right	Overturned	NULL
2004	W	43.00	No Injury	MV-Animal(Wild)	NULL	NULL
2004	W	43.76	No Injury	Ran Off Roadway-Right	MV-Fixed Object	Overturned
2004	W	44.65	No Injury	Ran Off Roadway-Right	Overturned	MV-Other Object
2004	E	44.65	Bruises And Abrasions	MV-MV	Overturned	MV-Fixed Object
2005	W	35.00	No Injury	MV-Animal(Wild)	NULL	NULL
2005	W	35.97	No Injury	MV-Animal(Wild)	NULL	NULL
2005	W	37.00	No Injury	MV-Animal(Wild)	NULL	NULL

Table 4-8: Crash History Summary of the US-40 Study Section, MP 35-MP 45 (2003-2005) (continued)

Year	Direction	Milepost	Severity	Accident Type 1	Accident Type 2	Accident Type 3
2005	W	37.43	Fatal	Ran Off Roadway-Right	Overturned	Ran Off Roadway-Left
2005	W	37.60	No Injury	MV-Animal(Wild)	NULL	NULL
2005	E	37.90	Broken bones or bleeding wounds	Ran Off Roadway-Right	Ran Off Roadway-Left	Overturned
2005	W	40.00	No Injury	Ran Off Roadway-Left	MV-Other Object	NULL
2005	W	40.30	Possible Injury	Ran Off Roadway-Right	Overturned	MV-Other Object
2005	W	40.30	No Injury	Ran Off Roadway-Right	MV-Fixed Object	NULL
2005	E	41.30	No Injury	MV-Animal(Wild)	NULL	NULL
2005	E	41.90	No Injury	MV-Animal(Wild)	NULL	NULL
2005	E	41.90	No Injury	MV-Animal(Wild)	NULL	NULL
2005	W	43.00	No Injury	MV-Animal(Wild)	NULL	NULL
2005	W	43.40	No Injury	MV-Animal(Wild)	NULL	NULL

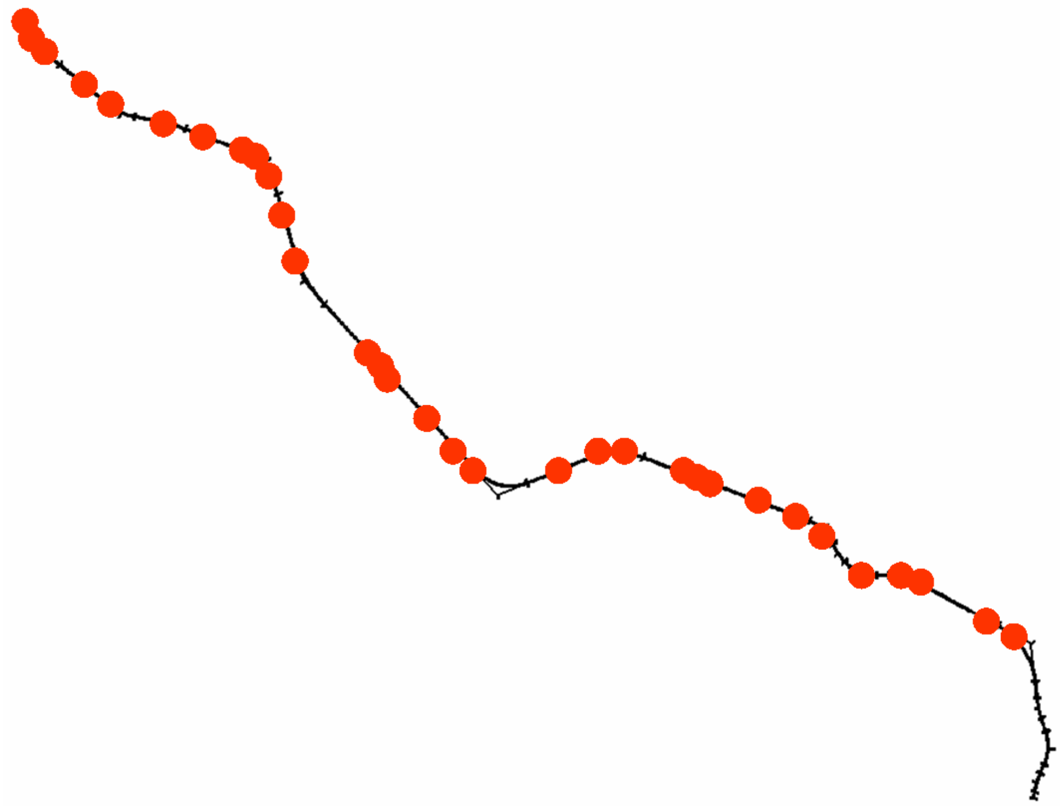


Figure 4-14: Plot of Crashes with Wild Animals in the US-40 Study Section from 2003 to 2005

In Figure 4-14 it is apparent that the crashes are scattered randomly throughout the study section, which makes it difficult to determine if any specific locations are more problematic than the others.

In order to identify locations with a high number of crashes caused by highway design it is necessary to focus on non-animal crashes. Figure 4-15 shows the locations with non-animal crashes. These crashes consist of vehicle collision, running-off roads, collision with static objects, etc. These non-animal crashes were plotted separately by the direction of travel, westbound and eastbound, as shown in Figure 4-16. Two locations seemed to have more crashes than other locations in the study section and their vertical alignments were subsequently examined for safety.

Figure 4-15: Plot of Non-Animal Crashes in the US-40 Study Section, From 2003 to 2005

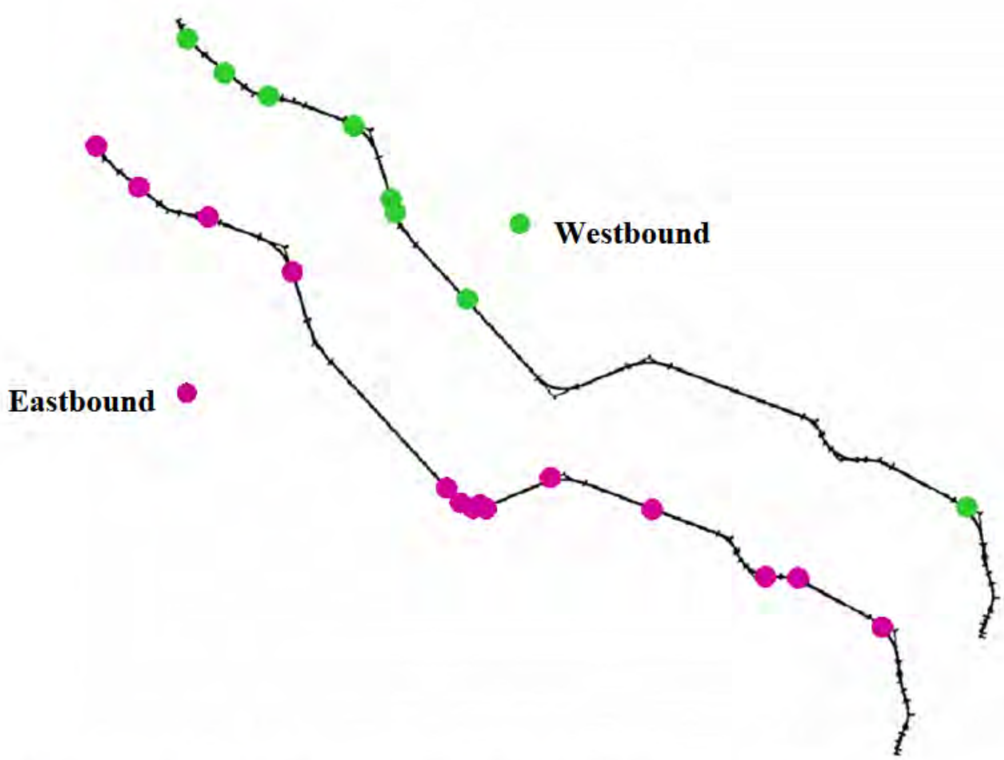


Figure 4-16: Plot of Non-Animal Crashes by Direction in the US-40 Study Section, 2003 to 2005

In Figure 4-15 one can immediately identify locations that could be problematic, such as the small curve at the mid location of the study section. Figure 4-16 gives another view of crash occurrence trend in the study section. The westbound has significantly more crashes than the eastbound, which makes one to think the approach to this small curve might have some geometric design issues. At this segment in the westbound direction, the highway's upslope begins, which may give a compound effect on crash occurrence. Figure 4-17 provides additional information regarding the vertical alignment of the section. Around MP 40, there is a sag vertical curve where horizontal curve change from a curve to a tangent. This combination of horizontal and vertical curve may have contributed to a higher number of crashes at this segment of the study section.

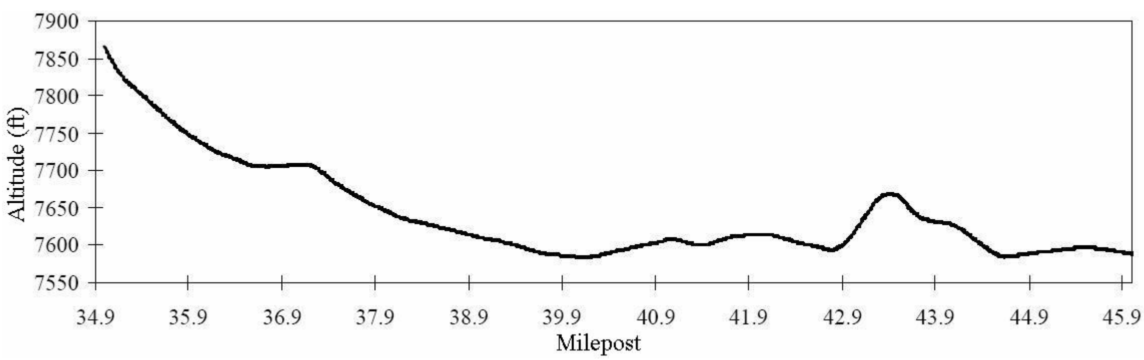


Figure 4-17: Vertical Alignment of the US-40 Study Section

Based on the discussions given so far, one can identify locations that can be "hot spots," as shown in Figure 4-18. Figure 4-18 shows possible four "hot spots" which are located approximately at MP 37, MP 38, MP 40, and MP 41. These spots are all related to tangent-to-curve transition points or on a tight curve. Other factors also need to be considered because the alignment may not be the sole cause for these crashes, including the obstacles along the highway (such as high hills and pavement condition), inefficient traffic signs, and so forth.

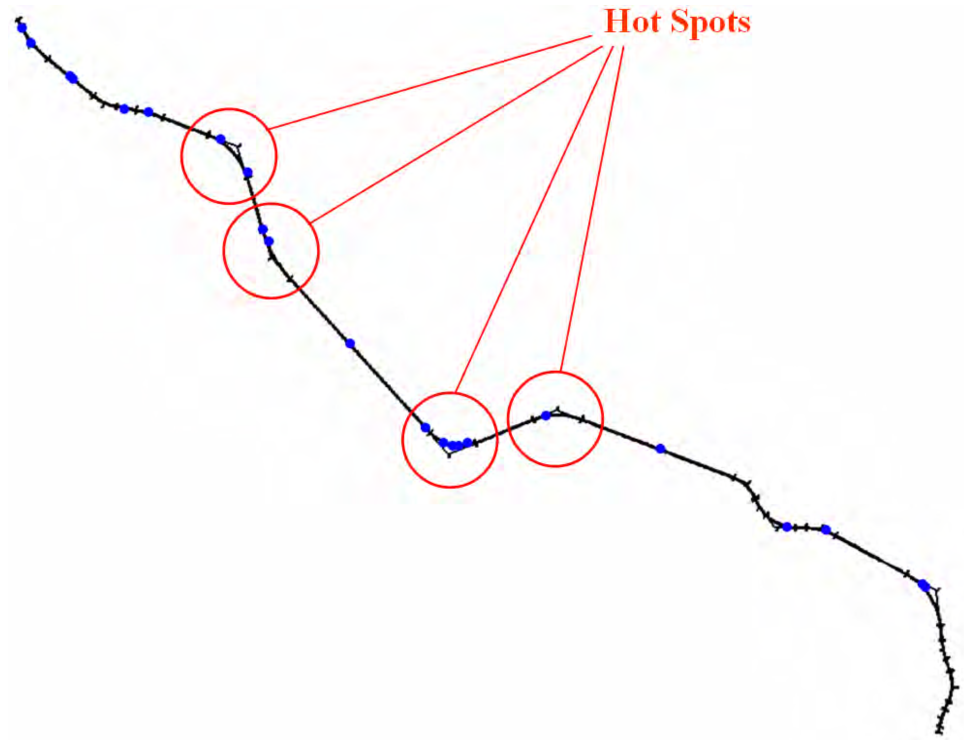


Figure 4-18: “Hot Spots" of US-40 Study Section

In conclusion, the crash prediction by CPM with the crash history appeared very dissimilar because 60 percent of the crashes at this site were caused by wild animals, while the crash prediction model without crash history assumes only 30 percent animal-related crashes.” Because the CPM does not provide a crash history input option for wild animal-related collisions, crash predictions by CPM should be used with caution for highway sections with a large number of crashes with wild animals.

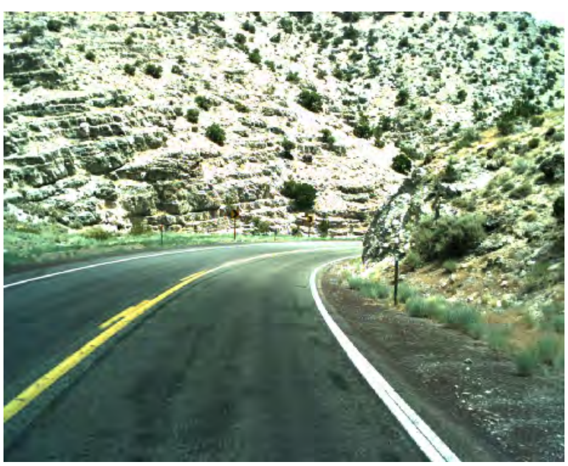
4.2 US-6 Study Section

Located in UDOT Region 4, the US-6 study section, from MP 22 to MP 28 was selected for its high number of crashes. Several improvements have been made on this section over the years, and the most recent and major rehabilitation took place in 2005. Because the GPS data used for this study were collected before this major rehabilitation, the changes that were made by the rehabilitation work was not considered in the analysis.

4.2.1 Current Condition of the US-6 Study Section

Two sets of photographs of the study section are given in Figure 4-19 and Figure 4-20 to help the readers visualize the section. The photos in Figure 4-19 were copied from the Roadview Explorer website (UDOT 2007a). In general the road conditions of the study section are good; the pavement markings are clear, and the pavement is in good condition. Figure 4-20 shows two photos taken by one of the authors during fall 2007. Compared to the US-40 study section the valley is narrower at this study section and the cuts are closer to the travel way. Figure 4-21 is a map extracted from the UDOT database and it shows the location of the US-6 study section (UDOT 2008). Refer back to Figure 4-1 for the location of the US-6 study section, which shows the relative locations of the three highway sections selected for this study.

In addition, a stretch of this portion of US-6 including the study section was reconstructed in summer 2007. However, because the changes made to the study section had not been updated in the GPS database kept by UDOT at the time this study was conducted, the GPS data extracted from the photolog database still reflected the road alignments before the reconstruction. Hence, the effect of the reconstruction was not considered in the study.



(a) MP 26, Eastbound

(b) MP 23, Westbound

Figure 4-19: Photos of the US-6 Study Section in Summer 2005 (UDOT 2007a)

(a) MP 27, Westbound (b) MP 26, Eastbound

Figure 4-20: Photos of the US-40 Study Section in Fall 2007 (Taken by Kaitlin Chuo)

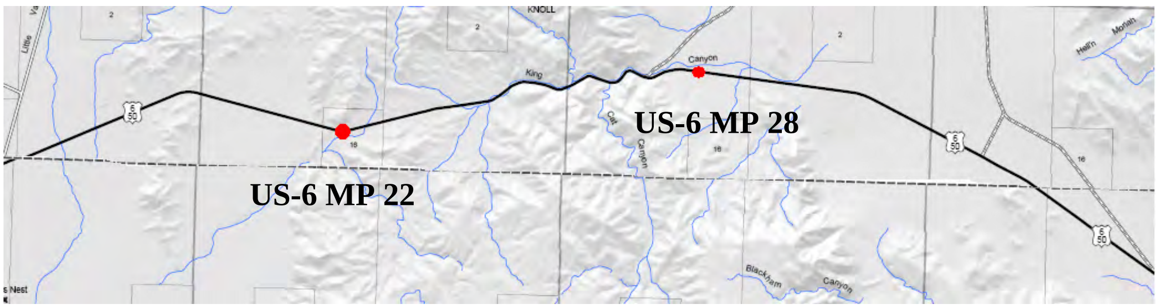


Figure 4-21: Location of the US-6 Study Section (UDOT 2008)

4.2.2 Centerline Alignments of the US-6 Study Section

Following the same method outlined previously and discussed in detail in Appendix, the centerline alignments of the study section were obtained and are summarized in Table 4-9 and Table 4-10 . As mentioned previously, the study section had major improvement work underway when the GPS data were collected; therefore, the outputs for this study section need to be interpreted with caution.

Table 4-9: Horizontal Alignment of the US-6 Study Section

Segment	Milepost		Radius (ft)
	From	To	
Tangent	22.00	22.01	---
Simple Curve	22.01	22.10	3500
Tangent	22.10	23.27	---
Simple Curve	23.27	23.50	12000
Tangent	23.50	24.35	---
Simple Curve	24.35	24.64	2800
Tangent	24.64	24.87	---

Table 4-9: Horizontal Alignment of the US-6 Study Section (continued)

Segment	Milepost		Radius (ft)
	From	To	
Simple Curve	24.87	25.04	1600
Tangent	25.04	25.05	---
Simple Curve	25.05	25.22	2800
Tangent	25.22	25.47	---
Simple Curve	25.47	25.55	1050
Tangent	25.55	25.57	---
Simple Curve	25.57	25.67	700
Tangent	25.67	25.71	---
Simple Curve	25.71	25.86	1950
Tangent	25.86	26.05	---
Simple Curve	26.05	26.14	5000
Tangent	26.14	26.17	---
Simple Curve	26.17	26.32	635
Tangent	26.32	26.40	---
Simple Curve	26.40	26.58	1200
Tangent	26.58	26.70	---
Simple Curve	26.70	26.79	550
Tangent	26.79	26.91	---
Simple Curve	26.91	27.06	520
Tangent	27.06	27.21	---
Simple Curve	27.21	27.47	1450
Tangent	27.47	27.63	---
Simple Curve	27.63	27.94	2900
Tangent	27.94	27.98	---

Table 4-10: Vertical Alignments of US-6 Study Section

Milepost	Back Grade (%)	Back Length (ft)	Forward Grade (%)	Forward Length (ft)
22.08	3.09	0.62	2.47	0.62
22.28	2.47	2.01	3.27	2.01
22.48	3.27	225.31	1.02	225.31
22.80	1.02	465.12	-3.64	465.12
23.25	-3.64	138.97	-2.25	138.97
23.47	-2.25	63.43	-2.88	63.43
23.71	-2.88	67.73	-2.43	67.73
24.06	-2.43	886.67	-4.97	886.67
24.31	-4.97	259.02	-3.24	259.02
24.55	-3.24	105.63	-3.47	105.63
25.00	-3.47	1.29	-3.04	1.29

Table 4-10: Vertical Alignments of US-6 Study Section (continued)

Milepost	Back Grade (%)	Back Length (ft)	Forward Grade (%)	Forward Length (ft)
25.69	-3.04	1226.00	-5.09	1226.00
26.07	-5.09	44.61	-3.60	44.61
26.19	-3.60	52.14	-4.91	52.14
26.44	-4.91	62.65	-6.48	62.65
26.59	-6.48	22.22	-5.92	22.22
27.14	-5.92	47.61	-4.56	47.61
27.68	-4.56	12.64	-4.98	12.64

From the alignment data obtained from InRoads, as shown in Table 4-9 and Table 4-10, the graphical result is also displayed in Figure 4-22. Figure 4-22 shows the surrogate centerline alignment of the US-6 study section with mileposts for tangent and curve segments. Compare Figure 4-21 and Figure 4-22 for similarity of the actual and surrogate horizontal alignments.

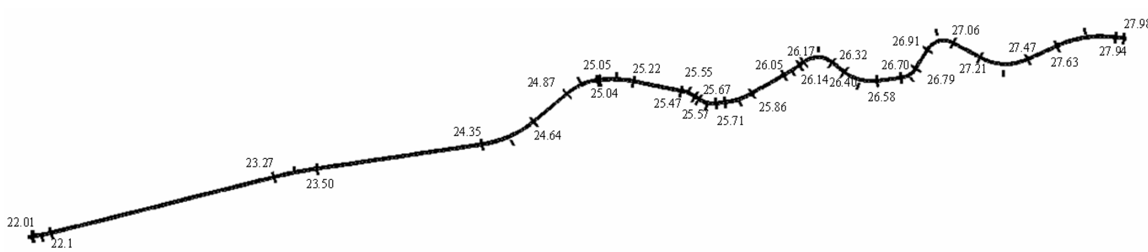


Figure 4-22: Surrogate Horizontal Alignment of the US-6 Study Section with Mileposts

4.2.3 Crash Prediction Results of the US-6 Study Section

To ensure the level of accuracy and minimize the differences in crash prediction estimates among the study sections, the same steps used for the US-40 study section was used for the US-6 study section. Table 4-11 shows the crash prediction results by the CPM in number of crashes from 2006 to 2008 and compares the crash history extracted from 2003 to 2005 (UDOT 2007b) against the predicted values. The three graphs shown in Figure 4-23, Figure 4-24, and Figure 4-25 visually present the data in Table 4-11. One must be cautious of the vertical scales used in the graphs when viewing them.

Table 4-11: Crash Prediction Results for the US-6 Study Section (Number of Crashes)

Milepost		No. of Crashes (2006-2008)			No. of Crashes (2003-2005)
From	To	with Crashes	w/o Crashes	Diff.	Crash History
22.00	22.01	0.00	0.00	0.00	0.00
22.01	22.10	0.03	0.03	0.00	0.00
22.10	23.27	0.38	0.28	0.09	2.00
23.27	23.50	0.05	0.06	0.00	0.00
23.50	24.35	0.20	0.28	0.01	0.00
24.35	24.64	0.08	0.09	0.01	0.00
24.64	24.87	0.05	0.05	0.00	0.00
24.87	25.04	0.06	0.06	0.00	0.00
25.04	25.05	0.00	0.00	0.00	0.00
25.05	25.22	0.05	0.05	0.00	0.00
25.22	25.47	0.06	0.06	0.00	0.00
25.47	25.55	0.03	0.04	0.00	0.00
25.55	25.57	0.01	0.01	0.00	0.00
25.57	25.67	0.16	0.05	0.11	1.00
25.67	25.71	0.01	0.01	0.00	0.00
25.71	25.86	0.05	0.05	0.00	0.00
25.86	26.05	0.04	0.05	0.00	1.00
26.05	26.14	0.09	0.03	0.06	0.00
26.14	26.17	0.01	0.01	0.00	0.00
26.17	26.32	0.07	0.07	0.01	0.00
26.32	26.40	0.02	0.02	0.00	0.00
26.40	26.58	0.06	0.07	0.01	0.00
26.58	26.70	0.03	0.03	0.00	0.00
26.7	26.79	0.18	0.06	0.12	1.00
26.79	26.91	0.20	0.03	0.17	2.00
26.91	27.06	0.52	0.08	0.44	4.00
27.06	27.21	0.04	0.04	0.00	0.00
27.21	27.47	0.08	0.09	0.01	0.00
27.47	27.63	0.04	0.04	0.00	0.00
27.63	27.94	0.09	0.09	0.01	0.00
27.94	27.98	0.01	0.01	0.00	0.00

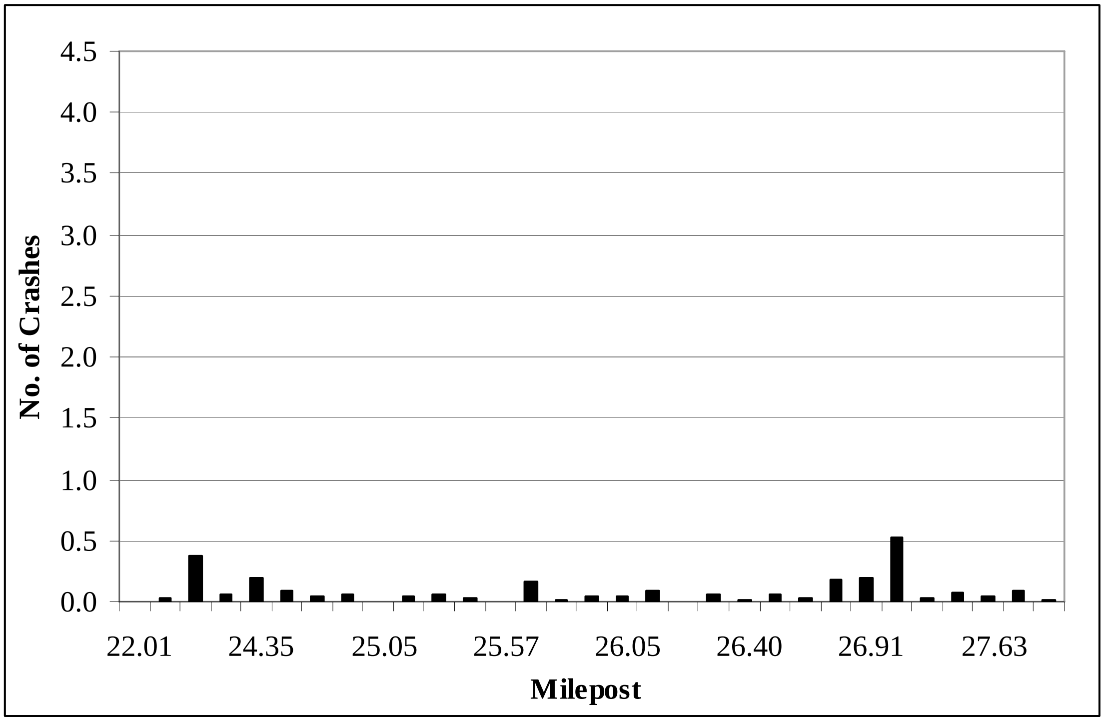


Figure 4-23: Plot of CPM Prediction Results of the US-6 Study Section (Number of Crashes), MP 22-MP 28 (2006-2008), Analyzed with Crash History

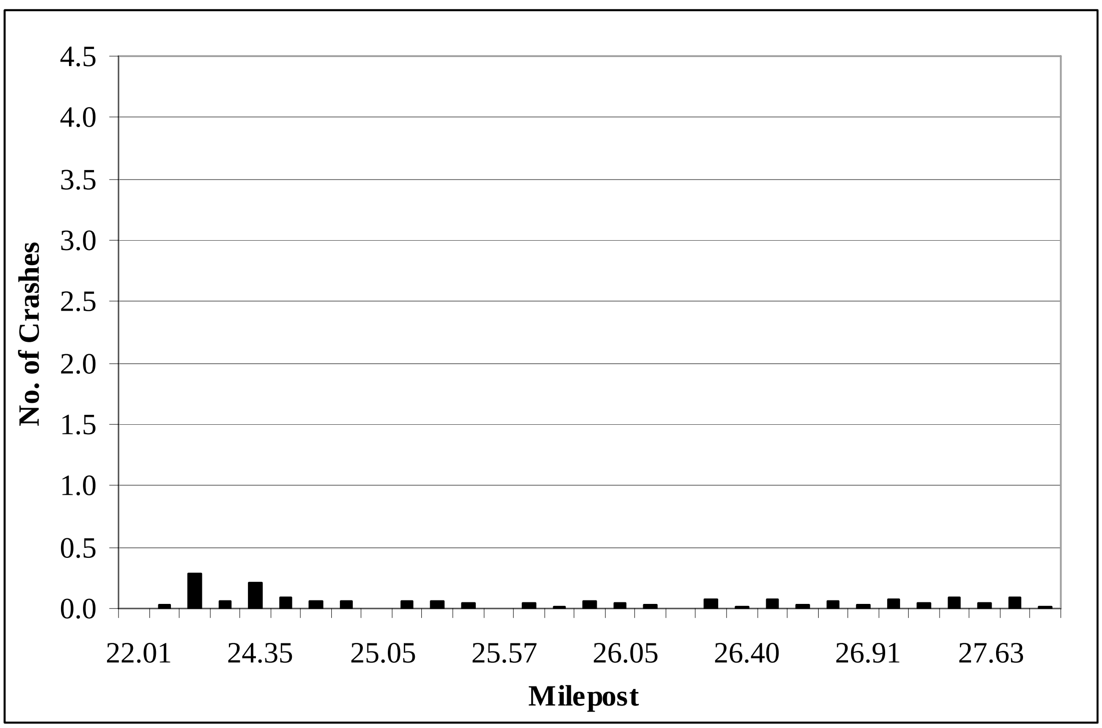


Figure 4-24: Plot of CPM Prediction Results of the US-6 Study Section (Number of Crashes), MP 22-MP 28 (2006-2008), Analyzed without Crash History

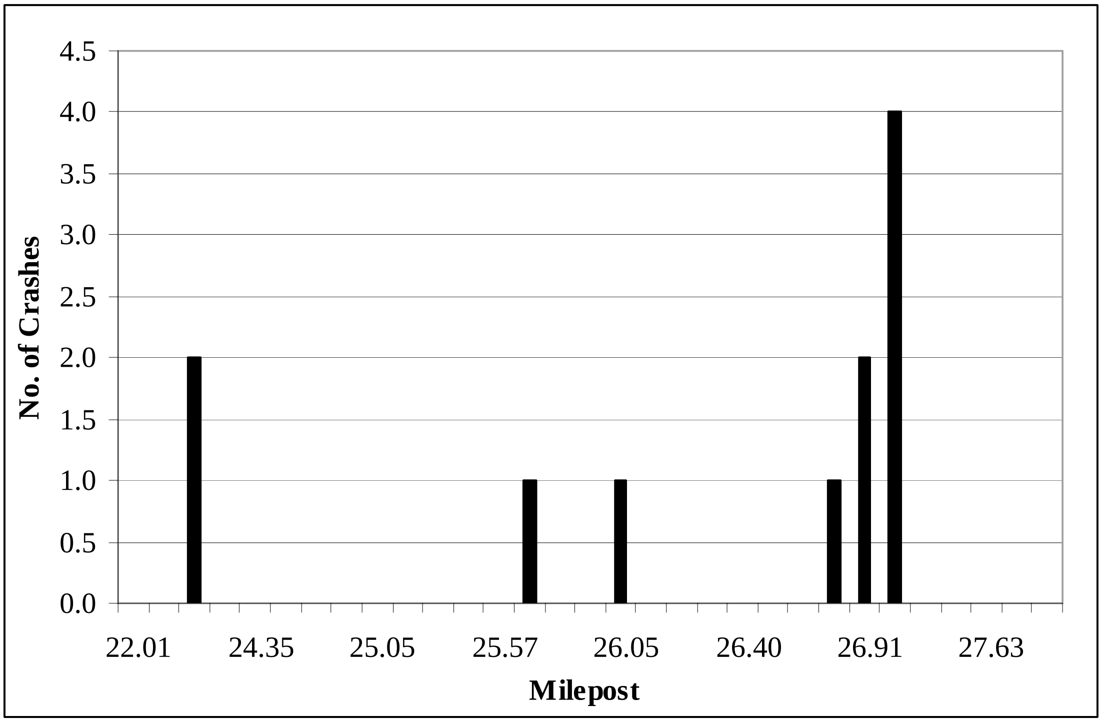


Figure 4-25: Plot of Crash History of US-6 Study Section (Number of Crashes), MP 22-MP 28 (2003-2005)

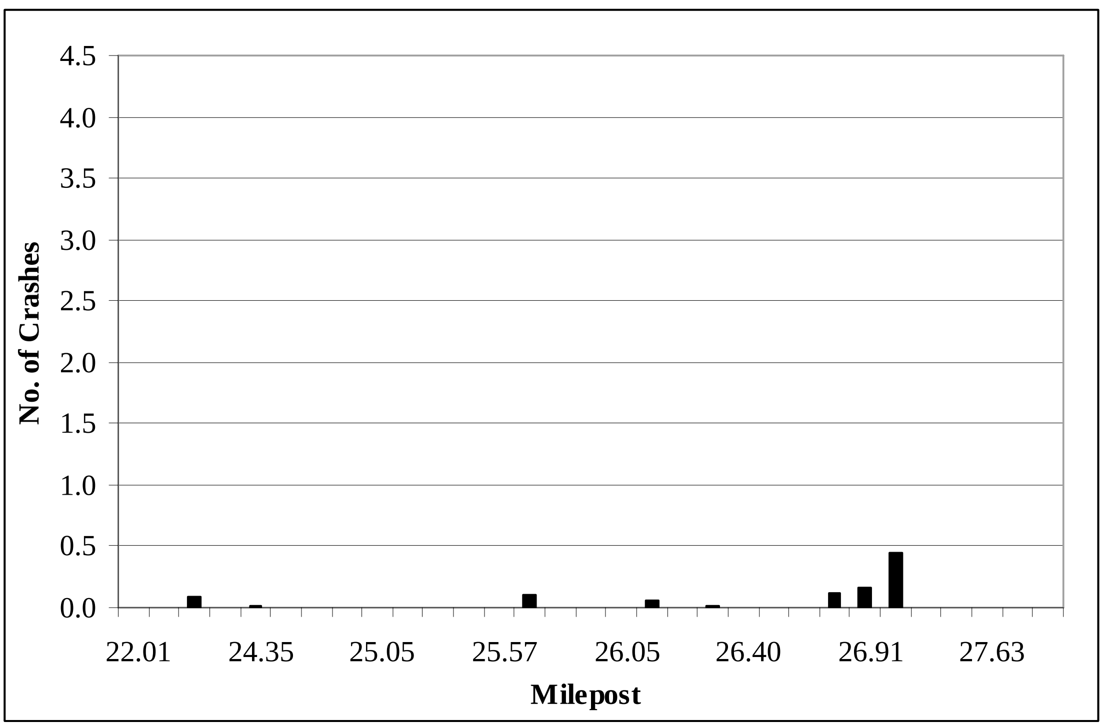


Figure 4-26: Plot of the Difference Between the CPM Results of US-6 Study Section in Number of Crashes Analyzed With and Without Crash History

A summary of statistics of the difference between the CPM results analyzed with and without crash history is shown in Table 4-12. It shows that the mean difference in the number of crashes between the two methods is less than 0.035, and the standard error of the mean is very small (0.016), resulting in the confidence interval of 0.004 and 0.066 at the 95 percent confidence level. From the statistics presented in Table 4-12 it can be said that the crash prediction without crash history is able to produce crash predictions that are similar to the crash prediction with crash history.

Again, graphical plots of the crash rate prediction results presented in Table 4-13 are also presented graphically in Figure 4-27, Figure 4-28, and Figure 4-29. Figure 4-27 shows higher crash rates near the beginning point of the study section and toward the end portion of the study section. This trend is similar to the actual crash history shown in Figure 4-28 and Figure 4-29.

Table 4-12: Statistics Summary of the Difference between the CPM Results in Number of Crashes Analyzed With and Without Crash History of US-6 Study Section

Mean	0.035
Standard Error	0.016
Median	0.004
Standard Deviation	0.086
Sample Variance	0.007
Kurtosis	16.569
Skewness	3.817
Range	0.440
Minimum	0.000
Maximum	0.440
Confidence Interval of the Mean (at the 95% Confidence Level)	0.004 – 0.066

Table 4-13: Crash Prediction Results for US-6 Study Sections, MP 22-MP 28 (crashes/MVMT)

Milepost		Length (mi)	Expected Crash Rate (2006-2008) (MVMT)			Crash Rate (2003-2005) (MVMT)
From	To		with Crashes	w/o Crashes	Diff.	Crash History
22.00	22.01	0.01	0.49	0.52	0.03	0.00
22.01	22.10	0.09	0.64	0.68	0.04	0.00

Table 4-13: Crash Prediction Results for US-6 Study Sections, MP 22- MP 28 (crashes/MVMT) (continued)

Milepost		Length (mi)	Expected Crash Rate (2006-2008) (MVMT)			Crash Rate (2003-2005) (MVMT)
From	To		with Crashes	w/o Crashes	Diff.	Crash History
23.27	23.50	0.23	0.50	0.53	0.03	0.00
23.50	24.35	0.85	0.49	0.52	0.03	0.00
24.35	24.64	0.29	0.60	0.65	0.05	0.00
24.64	24.87	0.22	0.49	0.52	0.03	0.00
24.87	25.04	0.17	0.70	0.76	0.06	0.00
25.04	25.05	0.01	0.49	0.51	0.02	0.00
25.05	25.22	0.17	0.62	0.67	0.05	0.00
25.22	25.47	0.25	0.49	0.51	0.02	0.00
25.47	25.55	0.08	0.95	1.06	0.11	0.00
25.55	25.57	0.03	0.49	0.51	0.02	0.00
25.57	25.67	0.09	3.65	1.16	2.49	22.84
25.67	25.71	0.04	0.49	0.52	0.03	0.00
25.71	25.86	0.15	0.71	0.77	0.06	0.00
25.86	26.05	0.19	0.50	0.53	0.03	11.3
26.05	26.14	0.09	2.09	0.64	1.45	0.00
26.14	26.17	0.03	0.49	0.52	0.03	0.00
26.17	26.32	0.15	0.92	1.02	0.10	0.00
26.32	26.40	0.08	0.50	0.53	0.03	0.00
26.4	26.58	0.18	0.77	0.84	0.07	0.00
26.58	26.70	0.12	0.51	0.54	0.03	0.00
26.70	26.79	0.09	4.24	1.37	2.87	22.99
26.79	26.91	0.11	3.65	0.54	3.11	37.10
26.91	27.06	0.15	7.42	1.14	6.28	57.13
27.06	27.21	0.16	0.5	0.53	0.03	0.00
27.21	27.47	0.25	0.69	0.75	0.06	0.00
27.47	27.63	0.16	0.50	0.53	0.03	0.00
27.63	27.94	0.31	0.61	0.66	0.05	0.00
27.94	27.98	0.04	0.50	0.53	0.03	0.00

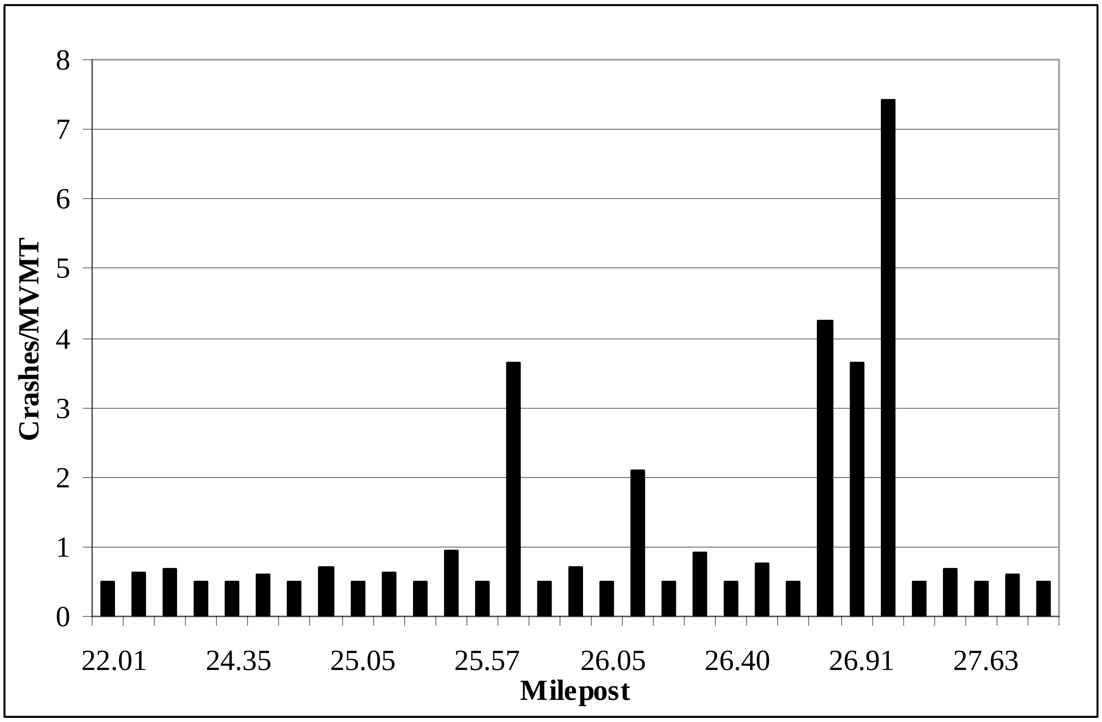


Figure 4-27: Plot of CPM Prediction Results of the US-6 Study Section (Crashes/MVMT), MP 22-MP 28 (2006-2008), Analyzed with Crash History

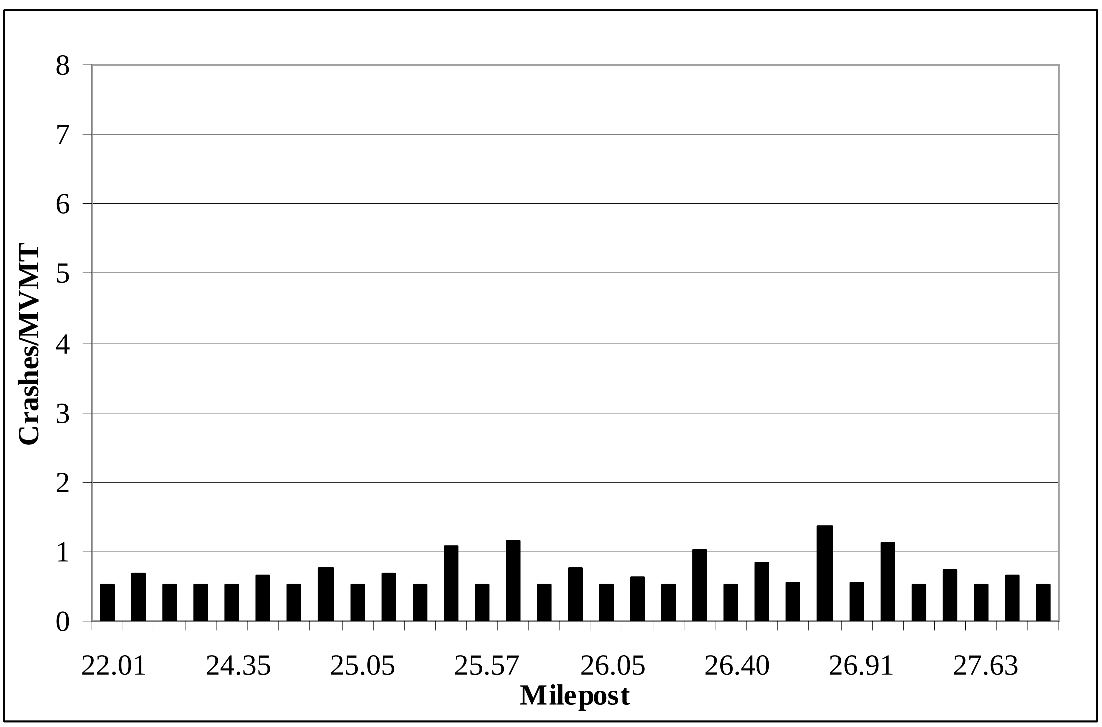


Figure 4-28: Plot of CPM Prediction Results of the US-6 Study Section (Crashes/MVMT), MP 22-MP 28 (2006-2008), Analyzed without Crash History