N C H R P
17-54

CONSIDERATION OF ROADSIDE FEATURES IN THE HIGHWAY SAFETY MANUAL

WORK PLAN

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NCHRP Project 17-54

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WORK PLAN

The following is the work plan for project 17-54. The plan consists of part four of the original proposal with some modifications to account for comments and suggests from the panel. The budget and schedule sections from the proposal are also included as is the progress report summary form to be used in the quarterly progress reports. The proposed project consists of eleven tasks. The task description provided by the project panel is provided below for each task in an italicized font and then a description of the activities in each task is provided by the research team.

The proposed project consists of eight tasks. The task description provided by the project panel is provided below for each task in an italicized font and then a description of the activities in each task is provided by the research team.

Task 1. Literature Review

Conduct a literature review of the analysis methods to quantify lane departure crashes including those used in the HSM and RSAP.

There is a long history of the use of both crash-based and encroachment-based methods in roadside safety analysis dating back to at least 1974. The HSM procedures for the rural two-lane safety predictions are based on work by Vogt and Bared [Bogt98]; however, the actual treatment of the roadside information originated from the work by Zegeer et al. in the 1980s [Zegeer88]. As the HSM predictive procedures evolved, additional research expanded the use of predictive methods to the rural multi-lane highways as well as the urban and suburban arterials. Each of these supplemental methods in some way incorporated roadside elements into the safety analysis; however, their source information varied considerably. Research specific to the roadside environment, on the other hand, has been limited in the HSM and focused primarily on select CMF conditions.

The literature devoted to cost-benefit methods in roadside safety, encroachment modeling, severity modeling is extensive going back as far as Hutchinson in 1962 and proceeding right up to present-day on-going NCHRP projects like Projects17-11, 17-22, and 22-27.[Hutchinson62, Bligh08, Ray10] In his Ph.D. dissertation, Ray provided an extensive review of the research related to probabilistic modeling of roadside crashes as of 1993.[Ray93] Turner wrote an NCHRP Synthesis report in 1994 collecting the latest research on severity indices of roadside features. [Turner94] In addition there are several on-going NCHRP projects that either are using RSAP, are directly working on improved methods that could be integrated into a new version of RSAP.

Miaou has used “accident-based” predictive models for reported run-off-the-road (ROR) crashes to estimate roadside encroachment rates and the severity of roadside slope roll over crashes. By exploiting the probabilistic relationship between encroachment and run-of-road crash events, the method tried to combine the strengths of both the accident-based and encroachment-based approaches, and proved successful. [Miaou96, Miaou97 and Miaou01] The results indicated that the proposed method could be a viable approach to using the same data and coordinating the HSM and RSAP results.

As very briefly explained in the description of this task and the background section, the literature to be searched, reviewed and summarized is extensive but, fortunately, several members of the research team already have several decades each of working with and contributing to this literature. For example, Dixon has many years of experience in developing and overseeing the development of the HSM CMFs in her role as an academic researcher and as the Chair of the HSM Research Subcommittee for the first edition of the HSM. Ray and Miaou each have decades of experience with probabilistic crash modeling; Miaou has extensive experience with developing models based on observed crash data; and Gabler is involved in assessing and collecting new crash data with enhance roadside elements. Since members of the research team already have much of the existing literature and have used it in many past projects, the literature review task should be both comprehensive and efficient.

Task 2. Identify CMFs and Data Sources

Identify CMFs and available data sources related to lane departure crashes from completed and ongoing research projects.

Highway safety engineers have continued to use a two-pronged strategy to reduce the frequency and severity of ROR crashes, namely keeping vehicles on the road and making the roadside more forgiving for errant vehicles. The former focuses on countermeasures that improve the travelled-way geometry and environment to reduce on-road events which lead to roadside encroachments. These countermeasures include straightening horizontal curves, flattening vertical alignments, installing shoulder and rumble strips, improving pavement friction, adding lanes and increasing lane widths, widening bridges, improving super-elevation, and improving visibility such as nighttime lighting conditions.

The latter strategy is aimed at increasing the chance of a recovery or reducing the severity of a crash if a collision does occur, given that a vehicle encroaches onto the roadside. These countermeasures include widening the clear zone (i.e., removing or relocating fixed objects, treating culvert ends, maintaining tree lines, etc.), flattening sideslopes, rounding the slopes of ditches, treating soil rutting and terracing reduce soft-soil tripped rollovers, and shielding roadside hazards with various types of barriers and attenuators. In essence, the former strategy attempts to mitigate crashes by keeping vehicles on the road and the later seeks to minimize the consequences when vehicles do leave the road.

Task 2a Identify CMFs

Given these two approaches to avoiding roadside crashes presented above, there are two types of CMFs of interest to this research. These two types of ROR CMFs include countermeasures that reduce the frequency of roadside encroachments (called on-road CMFs in this proposal) and countermeasures that increase the chance of encroaching vehicles to regain control or reduce the severity of a crash if a collision is inevitable (called off-road CMFs in this proposal). Currently several CMF sources are available. In 2007, the U. S. Department of Transportation released a *Desktop Reference for Crash Reduction Factors* that included most of the know crash reduction factors available at the time. Though a crash reduction factor is slightly different than a CMF, the CMF can be directly calculated from the CRF by subtracting the CRF from 1.0. In addition to the HSM, the new FHWA CMF Clearinghouse is now available and the developers of this site incorporated the values included in the 2007 publication as well as the HSM. CMFs available on the site are subjected to a star rating system to help users determine quality level of the CMFs. The FHWA CMF clearinghouse contains a variety of

CMFs, including both on- and off-road CMFs. An abridged version of the data available for on- and off-road CMFs from the FHWA CMF clearinghouse is presented in Table 1.

As depicted in the Table 1, many of the roadside CMFs currently on the FHWA clearinghouse have a low star rating indicating that their quality may not be appropriate for a wide-scale application or inclusion in a future edition of the HSM. In addition, for some candidate roadside CMFs (such as flatten roadside slope) there are multiple CMFs and each has a unique value. Members of the project team have been working with the clearinghouse developers at the University of North Carolina and the Federal Highway Administration to identify ways to help users identify the best CMF for a specific application. As a result of this research effort, the project team will make recommendations about existing roadside CMFs and how to clarify redundancies and/or improve quality of available CMFs located at the FHWA Clearinghouse as well as within the HSM.

Table 1. On-Road and Off-Road CMFs from FHWA's CMF Clearinghouse website

Study Titles	Countermeasure	CMF	Crash Severity	Star Quality Rating	CMF Type
1	Install impact attenuators	0.55	All	-2	Off
1	Widen bridge	0.56	All	-2	On
1	Improve superelevation	0.5	All	-2	On
1	Increase number of lanes	0.56	All	-2	On
1	Increase number of lanes	0.5	Property damage only (PDO)	-2	On
1	Widen lane (add 1 ft to both sides)	0.88	All	-2	On
1	Widen lane (add 2 ft to both sides)	0.77	All	-2	On
1	Widen lane (add 3 ft to both sides)	0.68	All	-2	On
1	Widen lane (add 4 ft to both sides)	0.6	All	-2	On
1	Widen lanes	0.51	All	-2	On
1	Improve pavement friction (groove shoulder)	0.73	All	-2	On
1	Improve pavement friction (grooving)	0.6	All	-2	On
1	Improve pavement friction (overlay)	0.72	Fatal,Serious injury,Minor injury	-2	On
1	Improve pavement friction (overlay)	0.71	Property damage only (PDO)	-2	On
1	Add two-way left-turn lane	0.63	All	-2	On
1	Add two-way left-turn lane	0.1	Fatal,Serious injury,Minor injury	-2	On

1	Add two-way left-turn lane	0.84	Property damage only (PDO)	-2	On
1	Implement maintenance and bituminous overlay	0.81	Fatal,Serious injury,Minor injury	-2	On
1	Implement maintenance and bituminous overlay	0.7	Property damage only (PDO)	-2	On
2	Convert 12-ft lanes and 6-ft shoulders to 10-ft lanes and 3-ft shoulders	1.13	All	3	On
2	Convert 12-ft lanes and 6-ft shoulders to 11-ft lanes and 2-ft shoulders	1.12	All	3	On
2	Convert 12-ft lanes and 6-ft shoulders to 10-ft lanes and 4-ft shoulders	1.2	All	3	On
2	Convert 12-ft lanes and 6-ft shoulders to 11-ft lanes and 3-ft shoulders	1.19	All	3	On
2	Convert 12-ft lanes and 6-ft shoulders to 12-ft lanes and 2-ft shoulders	1.16	All	3	On
2	Convert 12-ft lanes and 6-ft shoulders to 11-ft lanes and 4-ft shoulders	1.14	All	3	On
2	Convert 12-ft lanes and 6-ft shoulders to 12-ft lanes and 3-ft shoulders	1.11	All	2	On
2	Convert 12-ft lanes and 6-ft shoulders to 11-ft lanes and 5-ft shoulders	1.06	All	2	On
2	Convert 12-ft lanes and 6-ft shoulders to 12-ft lanes and 4-ft shoulders	1.04	All	2	On
2	Convert 12-ft lanes and 6-ft shoulders to 11-ft lanes and 6-ft shoulders	0.84	All	3	On
2	Convert 12-ft lanes and 6-ft shoulders to 12-ft lanes and 5-ft shoulders	0.87	All	3	On
2	Convert 12-ft lanes and 6-ft shoulders to 11-ft lanes and 7-ft shoulders	1	All	3	On
3	Install centerline rumble strips	0.71	All	4	On
3	Install centerline and/or shoulder rumble strips	0.79	All	4	On
4	Flatten sideslope from 1V:3H to 1V:4H	0.82	All	3	Off
4	Flatten sideslope from 1V:4H to 1V:6H	0.76	All	3	Off
5	New guardrail along embankment	0.56	Fatal	4	Off
5	New guardrail along embankment	0.53	Serious injury,Minor	5	Off

			injury		
5	New guardrail along embankment	0.93	All	3	Off
5	Change barrier along embankment to less rigid type	0.59	Fatal	3	Off
5	Change barrier along embankment to less rigid type	0.68	Serious injury,Minor injury	4	Off
1	Improve guardrail	0.74	All	-2	Off
1	Flatten side slopes	0.9	All	-2	Off
1	Install truck escape ramp	0.25	All	-2	Off
1	Install median barrier	0.65	All	-2	Off
1	Install or upgrade median barrier near gore area	0.44	All	-2	Off
1	Remove or relocate fixed objects outside of clear zone	0.29	All	-2	Off

Study Titles:
[1] Update of Florida Crash Reduction Factors and Countermeasures to Improve the Development of District Safety Improvement Projects
[2] Safety Effectiveness of Lane and Shoulder Width Combinations on Rural, Two-Lane, Undivided Roads
[3] Impact of Rumble Strips on Collision Reduction on BC Highways: A Comprehensive Before and After Safety Study
[4] Measuring the Goodness of Fit of Accident Prediction Models
[5] Handbook of Road Safety Measures

On-road CMFs are applied under the assumption that roadside conditions remain the same, therefore, once a vehicle encroaches onto the roadside it has the same probability of being involved in a ROR crash of any severity before and after implementing the countermeasure. For example, the chance of leaving the road will be decreased by flattening a horizontal curve but the degree of horizontal curvature does not help to predict what might be struck when the vehicle leaves the road. An important point to make here is that the HSM CMF are not generally limited to ROR crashes but include them as a component so the effect on ROR crashes may be somewhat obscured by the other crash types included especially for the on-road CMFs.

Off-road CMFs are applied under the assumption that travel way conditions remain the same (i.e., the likelihood of leaving the road is the same regardless of the width of the clearzone, the steepness of the foreslope or the presence of fixed objects), therefore, the expected number of encroachments is the same before and after the countermeasure is implemented but the number and severity of crashes might be different.

While Section 13.5 of the HSM presents general segment CMF information, it is also important to note that roadside CMFs exist in other locations in the manual. For each of the predictive methods, roadside CMFs are provided that range from qualitative (the roadside hazard rating) to quantitative (object offset and frequency as seen in the arterial section). In addition, the HSM lists several candidate treatments that suggest safety trends but have not been quantified at this time. It is the recommendation of our team that we will review all of these available CMFs or trends and then recommend to the project panel roadside CMFs that should be developed as well as existing CMFs that should be refined.

Task 2b Indentify Data Sources

This task will investigate the use of the following data sources as candidates for use in developing new roadside CMFs.

NCHRP 17-22 Database

The NCHRP Project 17-22 database is a set of 890 in-depth crash investigations of run-off road crashes collected primarily from 1997-2001 through supplemental National Automotive Sampling System (NASS) / Crashworthiness Data System (CDS) crash investigations. The dataset includes cases collected specifically in NCHRP 17-22 as well as run-off road cases collected in NCHRP 17-11 and the Federal Highway Administration (FHWA) rollover study. The Project 17-22 database contains specialized data elements describing barrier design, slope, and roadway geometrics needed for the analysis of the run-off road crash risk and injury outcomes. One of the research team participants (Virginia Tech) is currently performing extensive analyses of this dataset under NCHRP Project 17-43 to determine the optimal length of need for longitudinal, tree/pole impacts, rollover risk on side slopes, side impact injury risk, and the injury risk of occupant compartment intrusion in run-off road crashes. This database is a likely source of information that could be used to develop some new roadside CMF since it is one of the few crash data sets that include roadside information.

NCHRP 17-43 Database

NCHRP 17-43, being conducted by a portion of the research team (i.e.,Virginia Tech), will provide in-depth crash investigation data of more than 1,000 new road departure crash cases. Like 17-22, Project 17-43 will collect the specialized vehicle trajectory data and roadside, highway, and barrier geometric descriptions which will be ideal for the development of road departure CMFs. In addition, the Project 17-43 database will provide several enhancements over the Project 17-22 database. The 17-43 database will collect significantly more detailed data on the barrier component geometry and will collect improved vehicle trajectory descriptions. In addition, the 17-43 dataset will focus on newer vehicles which better represent the future fleet. The NCHRP 17-22 dataset is now more than eight years old. Because 17-22 was not an ongoing study, the database contains no case vehicles with the advanced airbags, side impact countermeasures, and frontal-offset crash intrusion prevention that are now commonplace on vehicles in the U.S. fleet.

A major enhancement is that Virginia Tech will conduct 17-43 as a prospective study in which the unique characteristics of a road departure crash will be collected at the time of the original NASS/CDS site visit. This approach should lead to a significant improvement in reconstruction accuracy over the retrospective approach used in 17-22. In these prospective investigations, the crash evidence will be substantially fresher, a damaged barrier will likely still be present for inspection, and tire skids marks or rutting needed for establishing vehicle trajectory will likely still be present.

The first phase of NCHRP 17-43 is now underway in which the data collection protocol is being developed. Should additional data elements be needed for the development of CMFs under the proposed NCHRP 17-54, the timing is ideal to consider these data elements for inclusion in the upcoming field investigations. This coordination will be facilitated by the fact that NCHRP 17-43 is being conducted by Virginia Tech which is also a member of this proposed research team.

Highway Safety Information System (HSIS)

The Highway Safety Information System (HSIS) is a collection of accident data from nine states paired with road and roadside information for each crash location which may be useful for this project. Of particular interest to the proposed project is the detailed guardrail data collected by Michigan in the late 1980's and early 1990's, which may provide a promising dataset for the development of road departure CMFs. Three years of data include information for roughly 20,000 individual lengths of guardrail that can be linked to crash locations and, according to the authors of the data guidebook, is a one of its kind database.

NASS/CDS

NASS/CDS provides a detailed record of approximately 5,000 crashes investigated each year. [NCSA05] To be included in NASS/CDS, at least one of the vehicles in the crash had to have been towed from the scene. The NASS/CDS database includes only crashes involving cars, light trucks, vans and sport utility vehicles. Heavy vehicles and motorcycles are not included as subject vehicles in the NASS/CDS database. Cases are selected for NASS/CDS investigation using a complex sampling strategy which oversamples certain types of crashes including fatal crashes, crashes involving hospitalized occupants, and crashes involving late model year vehicles among other factors. [NCSA05] NASS/CDS does not contain many of the specialized roadside components, e.g. barrier offset or barrier type that would be desirable for evaluation of roadside hardware effectiveness. However for several roadside safety studies, the research team has used the extensive photographs taken in each NASS/CDS case to provide this missing information. This task will evaluate the possibility of using this approach with NASS/CDS cases for the proposed project.

State Crash Data Analysis

States which are not part of the HSIS program may, in some cases, yield useful data for the development of CMFs for road departure crashes. The research team has conducted extensive analyses of the last 5-10 years of state accident data for Florida, Texas, and New Jersey for previous projects and will receive five years of accident data for Illinois and Virginia shortly. Several of these states are geocoded which may facilitate linking with roadside and highway data maintained by these states. While these datasets may not be sufficiently detailed to support in-depth research into all aspects of road departure crashes, they will help provide insights into the influence of the commonly recognized factors such as driver characteristics, roadway geometrics and environment.

In addition, some states that are members of the HSIS program have supplemental roadside data that is currently not distributed as a part of HSIS. For example, the State of Washington has one of the most comprehensive roadside databases available. Though at this time the Washington data is not yet available, members of the project team have direct connections with the State of Washington and will request that they consider allowing use of their database for this research effort. Their comprehensive roadside database combined with the HSIS companion data would provide a robust data source for this research effort.

Longitudinal Barrier Special Studies (LBSS)

The research team will investigate the feasibility of using the Longitudinal Barrier Special Studies (LBSS) database to determine the frequency and severity of road departure crashes. Perhaps the most in-depth longitudinal barrier crash data collected prior to the components of the NCHRP 17-22 database, the LBSS, was collected in tandem with the National Automotive Sampling System (NASS) / Crashworthiness Data System (CDS) for approximately 600 barrier crashes occurring between 1982 and 1986. Although this is an older dataset, LBSS may provide additional insights into road departure crash characteristics. Researchers, including Erinle, et al. [Erinle94] and Hunter, Stewart, and Council [Hunter93] used this specialized database primarily to investigate injury differences between different barrier systems and investigate the performance of barrier end terminals. Elvik performed a meta-analysis of previous guardrail literature published between 1956 and 1993 to evaluate the safety effects of guardrails.[Elvik95]

The On-road CMFs discussed above, (e.g., highway characteristics and environment which affect encroachment frequency) were extensively studied during the development of the HSM. The NCHRP research projects which are the foundation for the various highway types will be reviewed as additional data sources for On-road CMFs. The following is a summary of crash prediction models and associated CMFs developed for the HSM from various projects focusing on models for road segments and their ability to estimate ROR crashes by severity:

- *NCHRP Project 17-18(4): Rural Two-Lane Highways:* This data can be used to estimate ROR crashes but is extremely limited based on predictions of total number of crashes from the model and the raw distribution of crashes and severity types. [Bellomo02]
- *NCHRP Project 17-29: Rural Multilane Highways:* This data cannot be used to estimate ROR crashes because crashes were grouped into single-vehicle and multi-vehicle crashes. The project did not subdivide single-vehicle crashes into finer categories, such as collisions with animals, fixed objects, other objects, etc.
- *NCHRP Project 17-26: Urban and Suburban Arterials:* This study could be used to estimate ROR crashes but it to is limited. The study used single-vehicle prediction models together with distributions of single-vehicle collisions for roadway segments by collision type. Collision types included: collision with parked vehicle, collision with animal, collision with fixed object, collision with other object, other single-vehicle collision and non-collision. [Harwood07]

Summary

As very briefly explained in the description of this task ROR CMFs and data sources exist. In some cases on-road CMFs need to be reanalyzed to better consider the possibility of run-off-road crashes and directionality of the CMF. Additionally, there are a good number of existing data sources for the development of off-road CMFs. Members of the research team already have extensive experiences working with these data sources and are actively engaged in collecting new data. Since members of the research team are already working with some of these data sources, this task should be both comprehensive and efficient.

Task 3. Survey of Practice

Survey practitioners, researchers, design consultants, and transportation agencies to assess their current model uses and needs as they relate to roadside safety during the planning and design stages. The survey should also solicit input about specific roadside concerns or areas of need regarding additional CMFs.

The survey will have several purposes. First, it will be important to identify the user communities of the existing programs including the RSAP, IHSDM, and Safety Analysis programs and determine how each user analyzes roadside safety as a result of the various programs. Similarly, it will be important to get information about the implementation and use of the new HSM.

It is believed that today most RSAP users are researchers and policy makers rather than practicing highway design engineers. For example, it seems to be common for engineers in a State DOT's design or standards division to use RSAP to explore policy implications of general design decisions but relatively unusual for designers working on specific highway design projects to use RSAP. Similarly as described previously, RSAP has been used by several researchers to explore a variety of policy issues like developing clearzone guidelines. One objective of the survey will be to determine the degree to which RSAP is used at the policy or planning level where CMFs may be a more appropriate.

This information will be important for several reasons. First, it is essential to know the target audience for each of these analysis tools and second, it is presumed that it would be more desirable to integrate RSAP into the routine design procedures of consultants and other specific highway project designers where the HSM Roadside CMFs would be more appropriate at the planning stages of projects and for policy creation.

Identifying these audiences will enable the research team to tailor roadside CMFs to those that are needed by practicing highway designers as well as researchers and policy makers.

Another critical aspect of the state of practice review will be to determine perceived needs by the transportation community. The survey will seek to determine if agencies have specific roadside environment assessment needs that should be elevated as high priorities for analysis in this project.

In several recent projects, the PI (i.e., Ray) has used the website SurveyMonkey.com to conduct internet-based practitioner surveys. The advantage to using a facility like SurveyMonkey is very sophisticated surveys can be developed and easily disseminated to recipients by email. Since the survey is an on-line survey, the participant base can be expanded to include a wide variety of researchers, policy makers, engineers and consultants. The results of the survey will be reported in the Interim Report developed as a part of Task 8.

Task 4. Compare HSM and RSAP

Document the strengths and weaknesses and differences between the HSM prediction models and RSAP and identify opportunities to provide consistency through updating data sources, base models, or modification factors.

The RDG includes software support for the encroachment-base approach through the Roadside Safety Analysis Program (RSAP). The Crash Prediction Module (CPM) of the Interactive Highway Safety Design Module (IHSDM) is a faithful software implementation of the HSM. RSAP models each ROR crash and the severity of each crash individually, whereas the IHSDM CPM predicts ROR crashes for a segment of a road, not distinguishing between either side of the road (except for divided roads where the median is treated separately) or different roadside features within a given segment.

The objective of this task is to document the differences between these two approaches, the strengths and the weaknesses of each and to identify opportunities to provide consistency between these two approaches. A direct comparison between the methods used in RSAP and the IHSDM CPM is difficult because of the inherent differences in the methods used to model ROR crashes. Regardless of the approach taken the resulting predictions of ROR crashes within a road segment for a given study period should be similar in magnitude.

The ongoing NCHRP 22-27, "Update to RSAP" project included a task to compare the IHSDM CPM and RSAP. The NCHRP 22-27 project team has completed this task. This research team proposes to build on the NCHRP 22-27 findings. NCHRP 22-27 documented the differences in user entered values, terminology used, and most importantly crash prediction values and reporting methodology. Some of the initial findings are indicated below.

- The IHSDM CPM allows the user to input the roadway and shoulder treatment, however, the current version of RSAP does not consider the roadway or shoulder treatment. RSAP2010, the pending update to RSAP will allow for the inclusion of some modification factors which influence ROR crashes. Reanalysis of this CMF could prove to be valuable in predicting encroachments and should be considered in this research under task 9.
- RSAP allows the user to input a current year ADT and the expected traffic growth over the project life. RSAP projects the traffic volume for each year of the project and then averages the traffic volume to determine an *average* traffic volume over the project life. This step reduces over or under-estimating encroachments based on the ADT of the design year or future year respectively. The HSM / IHSDM CPM allows the user to input the future traffic volume or current traffic volume. Crash predictions and modifications must then be developed on a per year basis for individual year traffic volume values. This extra step may be easily sidestepped by a user and a single traffic value applied, thereby over or underestimating over the design-life of the project. The user should, of course, analyze each year independently and sum each year's results to avoid under or over-predicting crashes.
- The IHSDM CPM allows the user to specify the Design Hour Volume (D) in percent and the Peak Hour Volume. Currently, this is not used for ROR crash predictions or modifications, however, this feature has the potential to be used extensively in ROR crash predictions. The current version of RSAP allows the user to specify an ADT, but

assumes a directional distribution of traffic equal to 50 percent. The user does not have an option to change the RSAP directional distribution. RSAP2010, the update to RSAP will allow users to enter a directional distribution of traffic.

- Regional crash data can be added to the HSM / IHSDM CPM for refinement of the analysis. The HSM further recommends the use of a regional calibration factor to ensure the predicted number of crashes adequately represent regional reported crash fluctuations (due to differences in report criteria, weather, terrain, etc.). The current version of RSAP provides the ability to adjust the analysis for regional influences through a User Adjustment Factor; however, the RSAP Engineering Manual gives little guidance on the application of this factor. RSAP2010, the update to RSAP will allow for the inclusion of regional adjustment factors.
- RSAP presents results of the expected crash costs for ROR crashes for each alternative, where the HSM / IHSDM CPM predicts total crashes for a segment of road and does not provide direct crash cost estimates.

Appendix A of the RDG provides a summary of RSAP. Within this appendix, an example problem is used to demonstrate the cost-effectiveness analysis procedure. This example problem concerns the hypothetical treatment of a culvert headwall on a resurfacing project. The sample problem has three alternatives for consideration:

- Alternative 1: Baseline – an unprotected headwall,
- Alternative 2: Install Guardrail and crashworthy end treatments, or
- Alternative 3: Extend the Culvert and re-grade the slopes.

Specific details of each alternative are in Appendix A of the RDG.

This analysis was conducted with all roadside features on the right side of the road, as the RDG documented in its example problem. As part of the RSAP algorithm, the direction of encroachment departures (i.e., left or right) are randomly selected, therefore encroachments to the left would not result in a crash for this example. The HSM models crashes by segment and/or intersection, not distinguishing between the different sides of the road, therefore the results of this example problem would include ROR crashes for the entire segment, regardless of where the roadside features are located (i.e., left side or right side).

The NCHRP 22-27 project team reanalyzed the RDG appendix A problem using (1) the results of RSAP 1.0 published in the RDG, (2) the latest version of RSAP (e.g., version 2.0.3) [RSAP03], (3) the version of the IHSDM CPM available at that time [IHSDM09], and (4) a manual solution developed using MS Excel noted as CEC in the figures. The results are presented in figures 2 and 3. As previously discussed, RSAP presents results of the expected crash costs for ROR crashes for each alternative, where the IHSDM CPM predicts total crashes for a segment of road and does not distinguish between the ROR crash severities, therefore cannot estimate the crash cost. RSAP manuals and the RDG suggests the use of the crash costs and a Benefit/Cost analysis of alternatives for the selection of a preferred alternative. The RDG Example Problem results for Incidents/Year are plotted in Figure 2 versus the RSAP recalculation of Accidents/Year and the excel analysis (CEC) in units of ROR crashes/year.

The IHSDM CPM presents results as total crashes over a study period. The example problem had a study period of 25 years, therefore, the total crashes were divided by 25 and plotted in Figure 2 for a direct comparison of magnitude with the RDG and RSAP values. The values presented in the RDG and generated by the IHSDM CPM software are approximately ten times larger than the other two software programs. Figure 3 is a modified version of figure 2, plotted at a 0.10 scale for improved visual comparison of the smaller scale results.

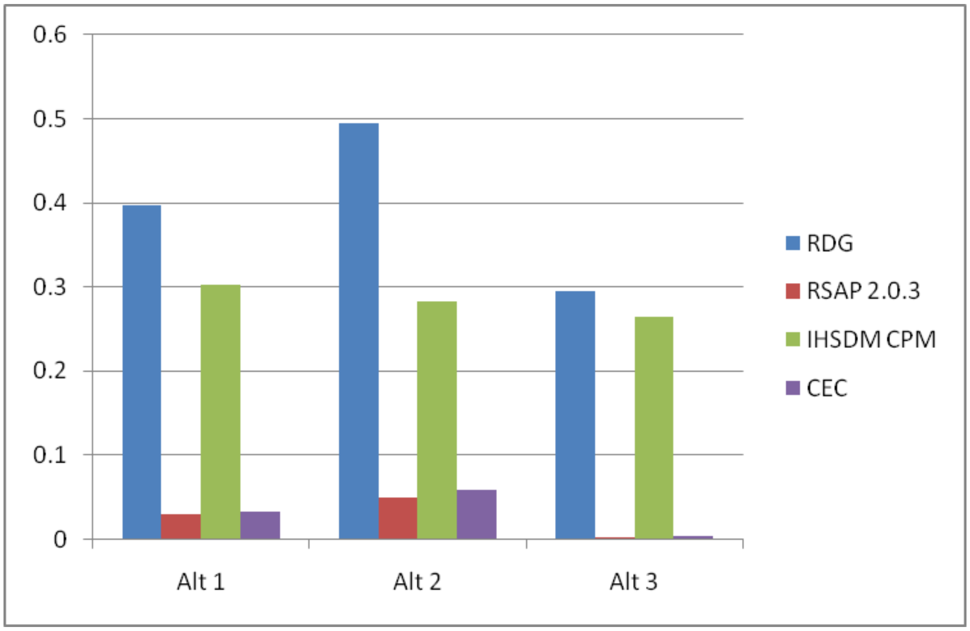

Figure 2. ROR Crash Predictions Using RSAP, IHSDM CPM, and Excel.
[note: Vertical axis represents crashes, accidents or incidents per year. A discussion of the vertical axis units is had in the text]

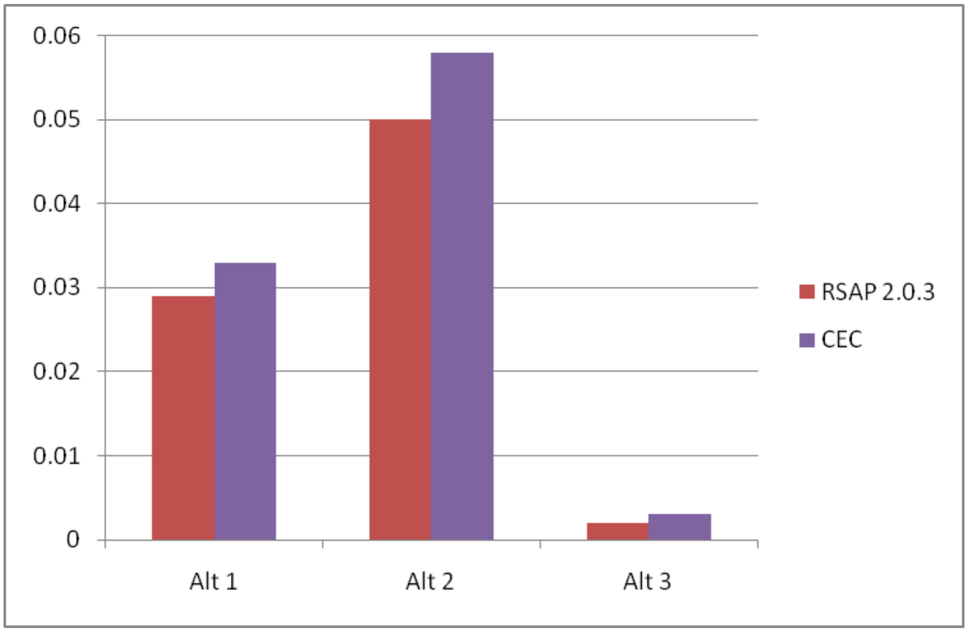

Figure 3. ROR Crash Predictions Using RSAP and Excel.

The results are presented using the terminology and units used by each respective program. The terms incident, crash, and accident are used more-or-less interchangeably. In the RSAP results, crashes or incidents imply an actual collision but the event may or may not be a police reported events whereas all the crashes reported by the IHSDM CPM are assumed to be police reported events.

One would expect or perhaps hope, that all four methods would result in similar estimates of run-off-road crashes. Unfortunately, the IHSDM CPM does not estimate crash cost but, rather, the frequency of crashes during the project life. The comparison, therefore, is based on the predicted number of crashes rather than the severity in so far as the comparison with the HSM / IHSDM CPM is concerned. One might also expect that the RSAP results would be somewhat higher than the HSM / IHSDM CPM since encroachment-based methods predict all ROR crashes whereas the CPM predicts only reported crashes.

The HSM / IHSDM also estimates all crashes on the segment not just ROR crashes. Fortunately, however, the HSM / IHSDM CPM estimates the number of each type of crash in its results tables. In the comparison below, the HSM / IHSDM CPM results are only the ROR portion of the results reported by the program.

The most obvious result of comparing the results from RSAP 1.0 (published in RDG) and RSAP 2.0.3 is that they are different by a factor of 10. King Mak, one of the original developers, was contacted and he said that a serious calculation problem was found in RSAP 1.0 and subsequently corrected in RSAP 2.0.3.

Direct comparisons between the CPM and RSAP are difficult, but one would expect results on the same order of magnitude. The methods used by the HSM do not recognize the addition of guardrail in alternative two, therefore the expected increase in crashes is not noted. The results obtained from the CPM are considerably higher than those predicted by RSAP version 2.0.3 (current version) and the workbook, along the order of ten times as many crashes. The CPM is predicting all ROR crashes. One could argue that this example problem only considered hazards on the right side of the road and therefore divide the CPM predictions in half, but the predictions are still considerably higher than those of RSAP and this workbook.

The RHR CMF used to modify the ROR crash potential results in only minor changes to the predicted ROR crashes, regardless of the RHR chosen. Refinement of this modification factor is needed to allow the CPM to accurately predict ROR crash potential. The RHR had relatively little effect on the results in the three alternatives. There is clearly a need to find a more systematic way of choosing an appropriate RHR that generates results more consistent with RSAP and verify that both approaches generate accurate results.

A sensitivity study of the RHR values, showed that the difference in crash frequency between an RHR of 3 and an RHR of 5 (i.e., the best to the worst) only changed the crash frequency by about 15 percent whereas the difference in frequency between the best and worst alternatives for RSAP 2.0.3 and the worksheet changed by a factor of 10. Roadside changes make a very significant change to the RSAP result and a relatively modest change to the HSM results. This research team proposes to build on NCHRP22-27 findings and use the findings to further document the strengths and weaknesses of each approach.

The RFP also calls for improved consistency between the approaches. Consistency and accuracy are key to maintaining the user's confidence in both software approaches and the safety modeling field. One could repeatedly model a given situation and get the same answer. This answer is consistent, but may be inaccurate. The current updating of RSAP will address the inaccuracies which have been noted in the literature [McGinnis99] and incorporate some of the HSM CMFs as encroachment adjustment factors. The research team proposes to evaluate the RHR and identify a more quantitative method that can then be used to reanalyze the roadside CMFs and, as a result, enhance both the accuracy and the consistency of these approaches. This reanalysis of the RHR would take place during Phase II under Task 9. A more detailed discussion is held under task 9.

Task 5. Sample Scenarios

Analyze sample scenarios for comparison between the HSM prediction models and RSAP. These scenarios should consider: rural 2-lane (level, rolling, and mountainous terrain), rural multilane (level, rolling, and mountainous terrain), and urban arterial. Long and short segment lengths as well as planning and design should be considered.

Comprehensive testing will be essential to make sure that the final products produce reliable, accurate results that are useful to practitioners. The NCHRP 22-27 project includes tasks for alpha and beta testing of the updated software. This testing requires the development of sample scenarios. Furthermore, NCHRP 22-27 has a task to re-write appendix A of the RDG which includes an example problem analyzed using RSAP. It is anticipated that each of these scenarios will have a wide range of roadside design and/or roadside hardware alternatives to consider with little variation in the highway geometry, terrain, or area type. The project team proposed to use the newly developed CMFs to compare results with those obtained from the update to RSAP.

The research team proposes to develop additional sample scenarios which will test the newly developed and reanalyzed CMFs. Particular attention will be paid to develop scenarios which test the reanalyzed highway geometric CMFs and the proposed RHR process. These scenarios will also be analyzed with RSAP and a comparison of the results will be completed.

Task 6. Recommendations for Future Development Efforts

Develop recommendations that as a minimum address: (1) model applicability; (2) appropriateness of continued parallel development of both methods for roadside safety assessment or, if one method should be chosen, for future development efforts; and (3) methods and coding for the possible inclusion of RSAP as a module in the IHSDM.

Based on the findings of the literature review (Task 2), the comparison of RSAP and the HSM (Task 4), and the analysis of the sample scenarios (Task 5), the project team will develop recommendations that address roadside safety model applicability. Pending the completion of Tasks 2, 4, and 5, the research team believes at this time that a new RHR procedure should be incorporating into the HSM and many CMFs which influence encroachment rates should be reanalyzed. Accomplishing these two major objectives will allow for “planning level” analysis of roadside designs using the HSM procedures and the IHSDM, a task which is currently time consuming and inefficient with RSAP.

The reanalyzed CMFs from this study should be incorporated into the encroachment probability model of RSAP to allow roadside designers to perform “design level” analysis of roadside design alternatives using the Benefit/Cost procedures outlined in the RDG and supported by RSAP. RSAP has the ability to evaluate roadside designs, regardless of segment length, thereby giving the designer the ability to remove and/or add individual roadside features (i.e., tree, pole, sign, ditch, end treatment, guard rail, etc.) within the segment. RSAP also has the ability to evaluate any roadside design feature, despite available crash records. As new roadside features are continually developed and deployed, this ability should be maintained.

Each model has particular advantages which should be maintained and exploited. A plan should be developed for continued parallel development to ensure reliability and accuracy of results between the approaches. Furthermore RSAP should be an available module in the IHSDM, which could be called by the User choosing to "design" the roadside. If the user chooses to "plan" the roadside, a roadside version of the CPM could be called.

Task 7. List of Roadside CMFs

Develop a prioritized list of roadside CMFs that should be evaluated for development and possible inclusion in future versions of the HSM.

The development of CMFs for the evaluation of ROR crashes should be considered in two categories, as previously introduced. These two types of ROR CMFs include countermeasures that reduce the frequency of roadside encroachments (On-road CMFs) and countermeasures that increase the chance of an encroached vehicle to regain control or reduce the severity of a crash if a collision is inevitable (Off-road CMFs).

On-Road CMFs

A good deal of On-Road CMFs exist, but require reanalysis for effective use in the analysis of roadside designs. One example is the horizontal curve CMF presented in the HSM. [HSM10] The HSM looks at the possible total reduction in crashes over a segment, where a roadside designer may be more interested in how the horizontal curvature of the travel way will impact the encroachment frequency.

The HSM CMF is presented as a function, shown here.

$$CMF = \frac{(1.55 * L_c) + \left(\frac{80.2}{R}\right) - (0.012 * S)}{(1.55 * L_c)}$$

Where:
Lc = Length of horizontal curve including length of spiral transitions, if present (mi)
R=Radius of curvature (ft)
S=1 if spiral transition curve is present; 0 if spiral transition curve is not present.

The HSM notes the effect of the spiral transitions are small for any given radius, therefore the presence of spiral transitions was neglected to simplify this example. Removing spiral transitions from the CMF results in the following equation:

$$CMF = \frac{(1.55 * L_c) + \left(\frac{80.2}{R}\right)}{(1.55 * L_c)}$$

Where:
Lc = Length of horizontal curve including length of spiral transitions, if present (mi) and
R=Radius of curvature (ft).

The resulting equation was graphed over a series of curve radii and lengths to determine the effect of and the limits of these variables. The results are presented in figure 4. The length of the curve appears to have a significant impact on the adjustment factor at short curve lengths and a decreasing impact as the length of curve increases. The length of curve has a dramatic effect at very short lengths (e.g, less than 100 feet), as would be expected.

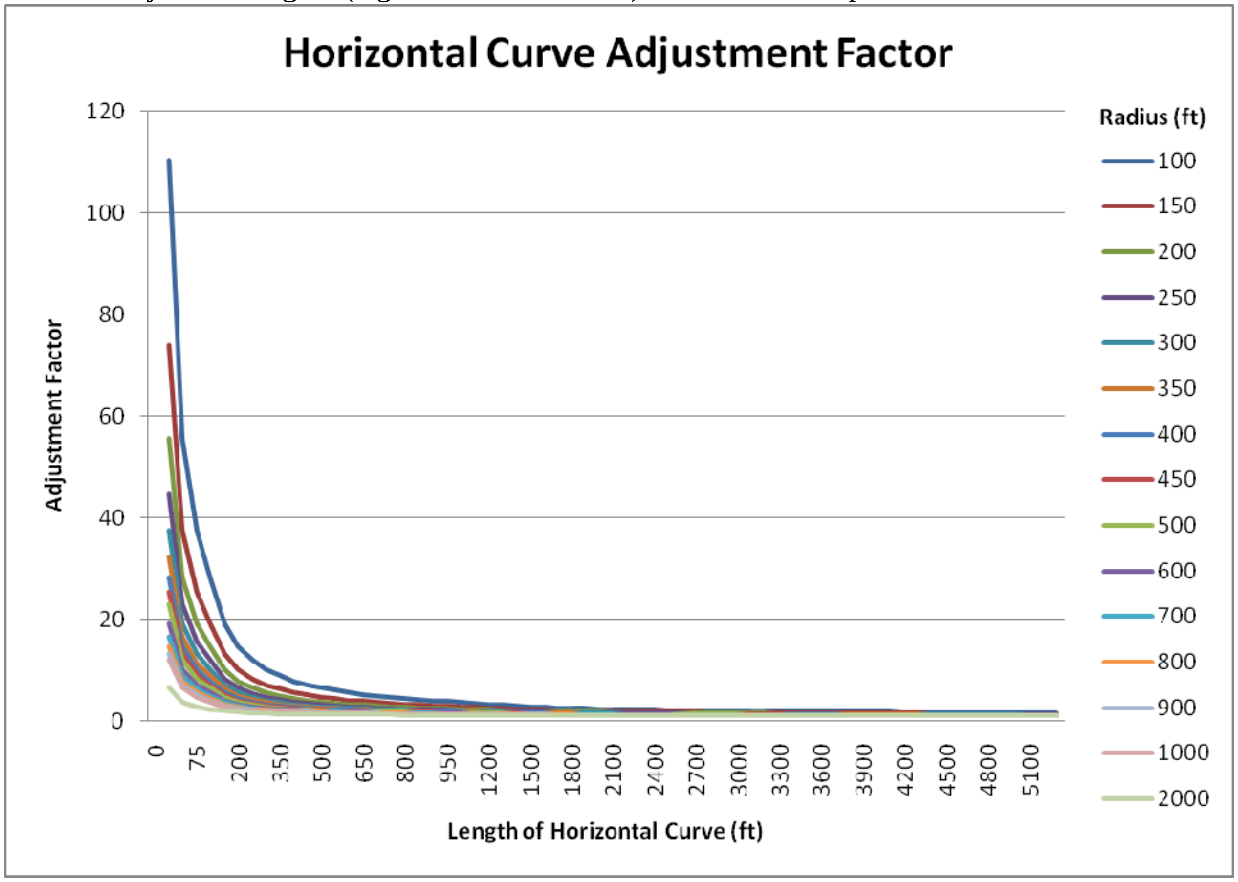

Figure 4. HSM Horizontal Curve Adjustment Factor

This CMF has a good deal of important variables, however the direction of travel is not included. Wright and Robertson conducted a study of highway characteristics which influence encroachment frequency and reported the findings by direction of travel.[Wright76] The Wright and Robertson data was originally presented with horizontal curves measured in degree of curvature. To remain consistent, the Wright and Robertson data has been converted from degree of curvature to radius to agree with the HSM CMF using this conversion.

Where:
R=the radius of curvature in feet
D=the degree of curvature

The Wright and Robertson results are shown in figure 5 with the HSM Horizontal Curve CMF superimposed. The calculation of the HSM CMF is based on a length of one mile. This value helps to remove the effect of length from the CMF and allow for a more direct comparison of the study results. Positive radii of curvature represent curves to the right whereas negative radii represent curves to the left. These adjustments do not correlate, but do suggest the same order of magnitude for curve adjustment factors at least when curving to the right. Additionally, a strong direction of travel adjustment is apparent.

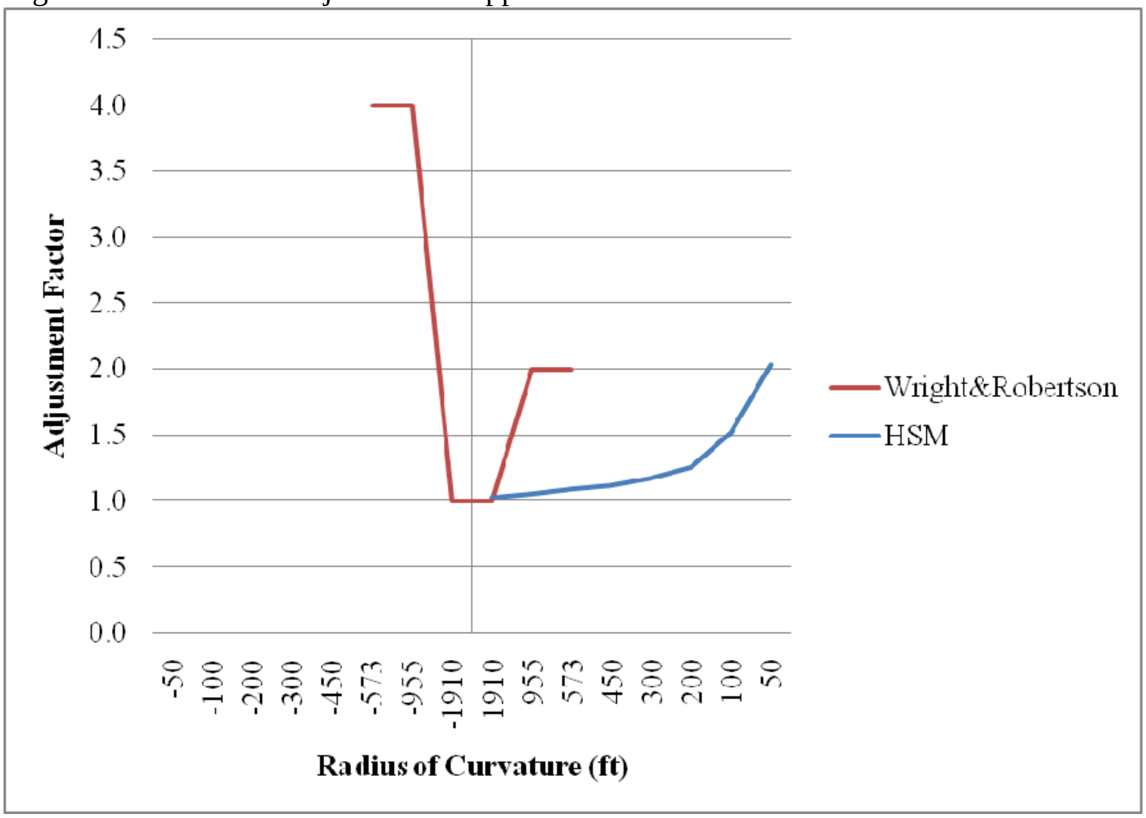

Figure 5. Comparison of Horizontal Curve Adjustment Factors.

In the absence of direction of travel data from the HSM curve adjustment CMF, symmetry has been assumed, resulting in figure 6. Clearly, there are discrepancies which require additional research.

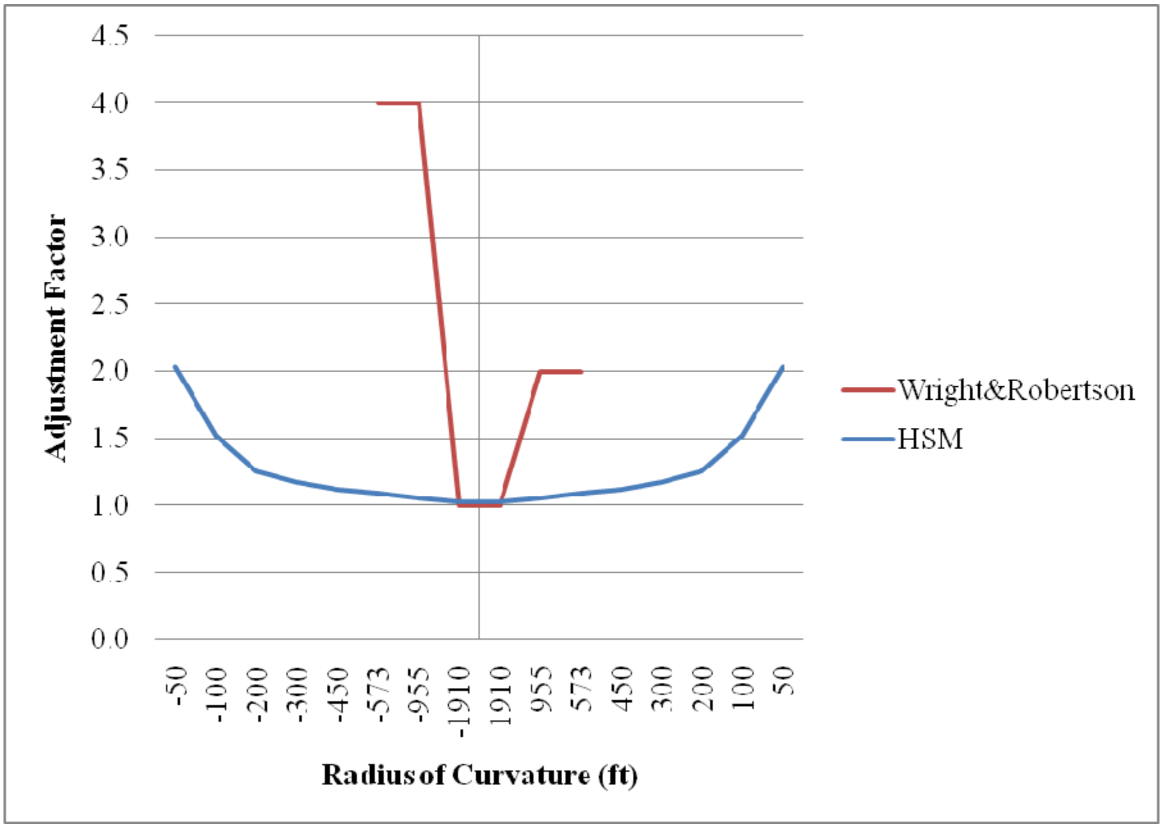

Figure 6. Horizontal Curve Adjustment Factors with HSM Symmetry Assumed.

Another example of an on-road CMF is the Access density CMF available in Table 13-58 of the HSM. [AASHTO10] This CMF is applicable to urban and suburban arterials. The adjustment is the same for undivided and divided highways and is shown in a modify format in Table 2. This access density adjustment factor has been incorporated into the RSAP update using the format shown in Table 2. NCHRP 22-27 re-analyzed the Cooper encroachment data [Cooper80], which resulted in the development of an access density adjustment factor for encroachments. The results of this research are presented in Table 3.

Table 2. HSM Access Density Adjustment

Pnts/mile	UnDivided	Divided
0	1	1
9	1	1
10	25	25
25	25	25
26	48.25	48.25
47	48.25	48.25
48	63.26	63.26
50	63.26	63.26

Table 3. NCHRP22-27 Access Density Adjustment Factor

Pnts/mile	UnDivided	Divided
0	1	1
1	4.831	3.279
2	9.728	6.521
3	15.067	7.671
4	17.687	8.166
5	20.594	8.693
6	21.691	7.517
7	22.198	5.665
1000000	22.198	5.665

These two access density CMFs are similar in magnitude, but each adjusts for different densities (i.e., one through seven or nine through fifty). These access density and horizontal curve CMFs are presented as examples of available CMFs to users of either the HSM and/or RSAP. These types of CMFs should be the first priority for this task. These existing CMFs should be reanalyzed if necessary, compiled and presented in a fashion that is usable across both platforms.

Off-road CMFs

As demonstrated earlier, there are only a limited number of high-quality Off-road CMF (i.e., CMFs used to evaluate roadside features after the vehicle has encroached onto the roadside). The research team believes efforts extended in this area should focus on design features which can be implemented along an entire roadway. Examples include roadside slopes, clear zones, and changes to fixed object density. The research team does not believe extensive effort should be extended toward developing CMFs for every type of roadside feature manufactured. Roadside safety features (i.e., longitudinal barriers, terminals, etc.) are being developed every day. These features are approved and installed on the roadway based on crash testing. It takes years of in-service crash data on each feature to develop a CMF for each feature. This is the strength of RSAP and where RSAP should be used. A prioritized list of off-road CMFs should include those types of features which crash data is available for and which are not man-made, but may be manipulated in construction to improve the safety performance. These features include clear zones, slopes, and changes to fixed object density. Additional CMFs to consider may include median width, median barrier installation, the treatment of ledge outcroppings, etc. As this research progresses, the research team will develop a prioritized list and submit it to the panel for review with the Interim Report.

Task 8. Interim Report and Meeting

Submit an interim report that includes the findings from Tasks 1 through 7 and an updated work plan for Phase II.

The project team will develop an interim report that documents the results of tasks one through seven and presents an updated work plan for Phase II. The interim report will contain at a minimum the following:

- A summary of the literature review from Task 1,
- A summary of the practitioner survey in Task 2,
- Documentation of the strength and weakness of both RSAP and the HSM with recommendations to provide consistency,
- A summary of analyzed scenarios comparison the HSM models and the RSAP encroachment method results,
- Recommendation that address model applicability, future develop of both models and the inclusion of RSAP in the ISHDM,
- A prioritized list of CMFs which influence roadside encroachments and CMFs for roadside features.
- A work plan for phase II of this project.

The interim report will be assembled and distributed to the panel such that it can be reviewed prior to the interim report review meeting. At the review meeting, the research team will present a summary of its findings and then devote considerable time to discussing the report, especially the work plan. The research team will revise the proposed work plan after the meeting to incorporate comments of the project panel and distribute the updated plan to the panel. It is likely that the panel and research team will have to prioritize the work plan and make adjustments to the available time and funding.

Task 9. Develop Roadside CMFs

Develop objective CMFs using the HSM protocols for the base conditions outlined in Volumes 2 and 3 of the Highway Safety Manual.

As indicated earlier, a regression model is used to develop the base model. The regression model uses observed number of crashes of a particular collision type and severity level on each site as dependent variable and uses traffic, geometric, and control variables of the site as independent variables (or covariates). Tables 4a and 4b shows various types of regression and safety performance function base models developed for the HSM for (4a) roadway segments and (4b) intersections. For each of these models, a variety of CMFs can be developed to help address conditions that vary from the base conditions. There are a wide variety of suitable statistical methods for development of these CMFs. The soon-to-be released FHWA *Crash Modification Factor Guidebook* recommends a wide variety of suitable study design for the development of CMFs. These include before-after comparison group studies, Empirical Bayes before-after studies, full Bayes studies, cross sectional studies, case-control studies, cohort studies, and assimilation-based CMF studies.

The safety performance functions have been separately developed for each of the two component types: roadway segment and intersections. Within each roadway component type, these models are further stratified by crash type, crash severity, and the adjustment factors considered in the models and, thus, in setting the nominal conditions. It is clear from the table that there is a significant variation in the types of base models and adjustment factors considered by these three projects. Thus, it is important to note that base models, as well as the CMFs, must be applied according to the conditions associated with each base model or CMF (e.g., roadway type, component types, crash type, and crash severity).

With very few exceptions, the negative binomial regression model and its variants were used in all the safety performance function development for the three functional road types currently included in the HSM. In addition, all models were developed on a per-year basis. None of the base models were specifically developed for the ROR crashes of interest to this project. The only one that comes close to be a ROR model is the single-vehicle collision model developed under NCHRP 17-26. The single-vehicle collisions included: (1) collision with parked vehicle, (2) collision with animal, (3) collision with fixed object, (4) collision with other object, (5) other single-vehicle collision, and (6) non-collision. Thus, both on-road and off-road crashes were included in the model. It is not clear from the project report what percentage of these crashes is off-road.

Table 4a. Base Models (Safety Performance Functions) for HSM: Roadway Segments

Classification Variable	**NCHRP 17-18(4): Rural Two-Lane Roads**	**NCHRP 17-26: Urban and Suburban Arterials**	**NCHRP 17-29: Rural Multilane Highways**
Segment Type	Two-Lane Undivided	• 2-lane undivided arterials (2U) • 3-lane arterials including a center TWLTL (3T) • 4-lane undivided arterials (4U) • 4-lane divided arterials (4D) • 5-lane arterials including a center TWLTL (5T)	• 4-Lane Divided • 4-Lane Undivided
Crash Type	All collision types combined	• Multiple-vehicle non-driveway collisions • Single-vehicle collisions • Driveway-related collisions • Vehicle-pedestrian collisions • Vehicle-bicycle collisions	• Divided: All collision types combined • Undivided: Intersecting direction and turning crashes, single-vehicle and opposing direction crashes, same direction crashes
Crash Severity	All severities combined (KABCO)	• All severities (KABCO) • Fatal and injury crashes (KABC) • PDO crashes (O)	• Divided: All and KAB • Undivided: All and KABC
Adj. Factors (Included in Regression Models)	• Geographical location (State) • Lane width • Shoulder width • Roadside hazard rating • Driveway density • Horizontal curvature • Vertical grade and other related grade measures	• Geographical location (State) • Shoulder width • On-street parking	• Geographical location (State) • Divided: None • Undivided: Right shoulder width and median + left should width
Base Conditions	• State: Minnesota • Lane width : 12 ft • Shoulder width: 6 ft • Roadside hazard rating : 3 • Driveway density: 5 driveways/mi • Horizontal curvature: 0 degrees per 100 ft arc • Vertical curvature: none • Vertical grade: Level (0%)	• States: MN and MI • Shoulder width = 6 ft • On-street parking = no on-street parking	• Divided: TX and CA combined • Undivided: CA, TX, and WA

Table 4b. Base Models (Safety Performance Functions) for HSM: Intersections

Classification Variable	NCHRP 17-18(4): Rural Two-Lane Roads	NCHRP 17-26: Urban and Suburban Arterials	NCHRP 17-29: Rural Multilane Highways
Intersection Type	• 3-leg intersections with STOP control on the minor-road approach • 4-leg intersections with STOP control on the minor-road approach • 4-leg signalized intersections	• 3-leg intersections with STOP control on the minor-road approach (3ST) • 3-leg signalized intersections (3SG) • 4-leg intersections with STOP control on the minor-road approaches (4ST) • 4-leg signalized intersections (4SG)	• 3-leg Unsignalized • 4-leg Unsignalized • 4-leg Signalized
Crash Type	All collision types combined	• Multiple-vehicle collisions • Single-vehicle collisions • Vehicle-pedestrian collisions • Vehicle-bicycle collisions	All collision types combined
Crash Severity	All severities combined (KABCO)	• All severities (KABCO) • Fatal and injury crashes (KABC) • PDO crashes (O)	• All severities (KABCO) • Fatal and injury crashes (KABC)
Adj. Factors (Included in Regression Models)	• Geographical location (State) • 3-leg STOP-controlled intersections: Roadside hazard rating (RHR) & Presence of right-turn lane on the major road (RT) • 4-leg STOP-controlled intersections: Number of driveways within 250 ft of the intersection on the major road (ND_1) & Intersection skew angle ($SKEW_4$) • 4-leg signalized intersections: Presence of protected left-turn signal phase (PROTLT), Percentage of minor-road traffic turning left ($PCTLEFT_2$), Grade rate for vertical curves within 250 ft of the intersection (VEICOM), Percentage of trucks entering the intersection (PTRUCK), and Number of driveways within 250 ft of the intersection on the major road (ND_1)	• Geographical location (State)	• Geographical location (State)
Base Conditions	• State: Minnesota • 3-leg STOP-controlled intersections: RHR = 2 and RT = 0 • 4-leg STOP-controlled intersections: $ND_1 = 0$ & $SKEW_4 = 0$ • 4-leg signalized intersections: PROTLT = no left-trun phase, $PCTLEFT_2$= 28.4%, VEICOM = no vertical curve, PTRUCK = 9.0%, ND_1= 0 driveways	• Geographical location: MN and NC combined (for multiple-vehicle collisions & single-vehicle collisions)	• 3-leg Unsignalized: CA State, no turn lanes, no illumination, median on major, adequate sight distance, and angle between -5^o and $+5^o$ • 4-leg Unsignalized: same as 3-leg unsignalized above • 4-leg Signalized: MN State

CMFs and Review Protocol in HSM

The CMF is defined as the ratio between the number of crashes per unit of time expected after a modification or measure is implemented and the number of crashes per unit of time estimated if the change does not take place. The modification or measure takes place often as a result of implementing a treatment or a program. It has been widely used by State and local highway safety engineers to evaluate the level of effectiveness of implementing a specific safety treatment and/or to determine the costs and benefits of alternative treatments. Among the many facets of highway program planning decisions, CMFs have been used in, e.g., economic analysis of safety treatments, treatment selection for short-term programming of safety improvements, project development to address safety aspects of large projects, and formulation of design policy.

The HSM presents information for quantifying the safety effects of various engineering treatments. The knowledge presented in Part D of the HSM is based on an extensive literature review of published highway safety research studies. This extensive review incorporated an evidence-based and rigorous assessment supported by statistical evidence of the accuracy and validity of studies. The literature review procedure included the following major steps:

- Step 1. Determine estimate of safety effect of treatment as documented in respective evaluation study publication;
- Step 2. Adjust estimate of safety effect to account for potential bias from regression-to-the-mean (RTM) and changes in traffic volume;
- Step 3. Determine ideal standard error of safety effect;
- Step 4. Apply method correction factor (MCF) to ideal standard error, based on evaluation study characteristics;
- Step 5. Adjust corrected standard error to account for bias from RTM and changes in traffic volume; and
- Step 6. Combine CMFs when specific criteria are met. In a limited number of cases, multiple evaluation studies provided estimates of safety effects post-implementation of same treatment at different locations with similar conditions.

The review protocol provided a scoring method for five types of evaluation studies that have been used to generate CMFs:

- Simple before–after evaluation study, which compares the crash experience of sites before the treatment is applied and after the treatment is applied;
- Before–after evaluation study with a comparison group, which is similar to a simple before–after study but adds a comparison group or control group that is not treated;
- Non-regression cross-section evaluation study, which compares the crash experience of sites with the treatment and sites without the treatment;
- Multivariable regression cross-section evaluation study, which produces statistical models for the crash experience of sites with the treatment; and
- Meta-analysis study, which combines the results of two or more evaluation studies, of any one of the types described above, of the safety effects of a treatment.

The scoring method, called method correction factor, took into account the potential bias associated with the selection of data and estimation methods and the completeness of documentation regarding the study's data and findings. In addition, the TRB HSM Task Force worked with the research contractor to develop an inclusion rule to determine suitable HSM CMFs that achieved acceptable levels of quality. This inclusion rule will be applied to all of the roadside CMFs developed as a result of this project and the project team will then be able to recommend with confidence any and all CMF values that achieve the acceptable standards necessary for incorporation into future editions of the HSM.

Unique Challenges to Developing Objective CMFs

It is envisioned that experience gained and lessons learned from earlier NCHRP projects will be valuable to the researchers in shaping the approach to the development objective CMFs. The development of roadside CMFs presents many challenges. These challenges include the presence of the unique characteristics of ROR crashes and the possible combination of countermeasures.

Making the decision to install certain safety devices, for example, is often a balancing act between crash severity and crash frequency. This is also the case in comparing the effects of installing alternative roadside features. Oftentimes an increase in crash frequency as a result of installing a roadside feature is offset by reducing the number of severe crashes. The importance of having accurate estimates of crash severity when making such decisions and comparisons is illustrated with the following two examples where a trade-off between crash severity and frequency is made.

- Installation of Guardrails: Bridge piers, utility poles, and severe embankments are hazards that, if encountered, may result in serious injury. In order to protect motorists, barriers can be placed in front of a roadside obstacle and should be much longer than the hazard in order to limit the risk of a serious crash when vehicles leave the road in advance of the barrier. Unfortunately, barriers also pose a risk to motorists. Installing guardrails may actually increase the number of crashes. As a result, for lower risk hazards, such as small objects and moderate slopes, the number of serious crashes associated with a guardrail can be greater than the number of similar impacts that would occur without the guardrail. In this situation, guardrail construction would increase the number of injured motorists compared to leaving the hazard unshielded. [Sicking09]

- Installation of Median Barriers: Within its performance limits, a median barrier is designed to contain and deflect an errant vehicle in a controlled manner with acceptable deceleration and low exit angle, resulting in a less severe injury to the occupants when compared with a cross-median crash. Installing a median barrier, however, will likely increase the number of barrier-crashes that would otherwise not have occurred. [Miaou05]

Using the protocols and the inclusion rule discussed above, the prioritized list of CMFs developed under Task 7 will be pursued under this task.

Task 10. Modification to RSAP

Depending on the outcome of Phase I, Task 6, prepare recommendations for potential modifications to the RSAP model.

Task six provides a discussion on the research team's approach to the parallel development of RSAP and the HSM and the incorporation of some on-road CMFs in the RSAP encroachment probability model. The NCHRP22-27 project team currently updating RSAP has moved all of the data outside of the software, which allows the underlying data to be more accessible to researchers and users, therefore, more easily updated. The Update to RSAP will include some adjustment factors (CMFs) which modify the base encroachment rate, including:

- Grade Adjustment Factor
- Horizontal Curve Adjustment Factor
- Land Width Adjustment Factor
- Multi-lane Adjustment Factor
- Access Density Adjustment Factor
- Rumble Strip Adjustment Factor
- Shoulder Width Adjustment Factor

NCHRP22-27 will produce a published set of specifications for the creation of the text files which contain each of these adjustment factors. Any CMFs developed under 17-54 which could be used to modify the base roadside encroachment frequency (on-road CMFs) should be converted to RSAP compatible data tables for use in the updated version of RSAP as well as the HSM.

Task 11. Final Report

Submit a final report documenting the entire research project. CMFs developed from this research should be documented in separate appendices that include, as a minimum, data sources, sample size, and analysis methodology

A final report will be prepared that assembles and documents all the research produced in this effort. The report will contain all the contents of the literature and survey included in the Interim Report and a discussion of the analyses and results developed. Also contain in this report will be the following:

- Appendices that include the data sources, simple size and analysis methodology used to generate the Roadside CMFs,
- Documentation on the new Encroachment Adjustment Factors and ASCI text files which meet the Look Up Table specifications of the Update to RSAP.

Anticipated Research Results

The anticipated result of this research project will

(A) Product –	The result of this project will be new roadside CMFs and adjustment factors for use in RSAP. This project will coordinate the HSM and Roadside Design Guide research efforts ultimately producing guidelines for the appropriate use of each document for the analysis of roadside designs.
(B) Audience–	The immediate audience for this research and the resulting guidelines will be roadside safety researcher, State DOT standards engineers and other policy makers as well as highway designers in the DOTs and consulting firms supporting the DOTs.
(C) Assessment –	We anticipate that the new CMFs and suggestions for use will be distributed with some future version of the HSM. Furthermore, we anticipate the CMFs will be converted to Adjustment Factors for use in the updated version of RSAP and distributed for some future use.
(D) Leadership –	The leadership of the AASHTO Technical Committee on Roadside Safety as well as the AASHTO Standing Committee on Highway Traffic Safety and their Subcommittee on Safety Management as well as the Federal Highway Administration will be crucial for the adoption of the new suggestions for use. In addition, each state DOT's Design Division or Design Standards Division will likely also play a key role in incorporating the new suggestions into the routine planning and design of roadsides.
(E) Activities –	It is essential that the products of this research and the Roadside Design Guide complement each other. Each document must meet the high standards the user community demands and each document must have clear guidelines for appropriate use. We believe that high-quality research coupled with implementation guidelines will lead to adoption by the highway design community.
(F) Criteria –	We believe this project will have a tremendous impact on how highway designers view the roadside during every design and help reduce roadside fatalities. The results of this project will be incorporated into the Highway Safety Manual and RSAP, improving analysis tools and awareness which should lead to improved designs.

Applicability to Highway Practice

The combination of this research team's extensive experience and the innovative research approach described in this proposal will maximize the chances for producing meaningful roadside CMFs, improve coordination between highway safety analysis tools and raise awareness of roadside design issues across the highway design profession. The CMFs developed in this study will be directly implemented as part of the Highway Safety Manual and RSAP, improving roadside consideration in the HSM and improving the quality of adjustment factors in RSAP. The implementation guidelines produced will provide highway designers with clear, concise knowledge of the appropriate use of each tool. The results of the project will likely be widely disseminated as a part of or companion to the Highway Safety Manual and the AASHTO Roadside Design Guide.

References

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PROGRESS AND SCHEDULE

The 27-month project schedule is shown below and the standard NCHRP Progress Schedule is shown on the following page. The schedule has been developed according to the critical dates indicated in the statement of work.

National Cooperative Highway Research Program

CONSIDERATION OF ROADSIDE FEATURES IN THE HIGHWAY SAFETY MANUAL

NCHRP 17-54

ROADSAFE LLC
P.O. Box 312, 12 Main Street
Canton Maine 04221

Assumed Start Date: 4 April 2011
Assumed End Date: 3 July 2013

		2011									2012													2013				
		A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
Task	***Title***	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
	Phase I																											
1	Literature Review																											
2	Indentify CMFs																											
3	Survey																											
4	HSM v RSAP																											
5	Sample Scenarios																											
6	Recommendations																											
7	Prioritized list of CMFs																											
8	Interim Report																											
	Phase II																											
9	Develop CMFs																											
10	RSAP modifications																											
11	Final Report																									review		
	Deliverables				▼			▼			▼	•		▼			▼			▼			▼		□			■

▼ Quarterly Report (Via e-mail, due the first week of the month)
□ Draft Final Report (due at the end of the month shown)
■ Final Report (due at the end of the month shown)
• Interim Report Panel Meeting

RESPONSES TO PANEL COMMENTS

CONSIDERATION OF ROADSIDE FEATURES IN THE HIGHWAY SAFETY MANUAL

NCHRP PROJECT 17-54

ROADSAFE LLC

17 JANUARY 2011

Panel comments are shown below in a regular font and the project team's response is shown in an italic faced font.

1. The objective of the project is to develop quantitative measures (Crash Modification Factors) for roadside features. The panel is aware that it may not be possible to develop CMFs for particular types of barriers and may only be possible to develop CMFs for longitudinal barriers or for longitudinal rigid and flexible barriers. Although the project will also consider recommendations for modifying RSAP the primary emphasis should be on developing quantitative measures for roadside features.

   The research team certainly agrees that the development of CMFs is the primary focus of the project. We expect that the experience gained and lessons learned from earlier and on-going NCHRP projects will be valuable to the researchers in the development of quantitative CMFs which address the reasons drivers encroach on the roadside and the frequency and severity which are a result of those encroachments.
   Task 6, "Recommendations for Future Development Efforts" and Task 10, "Modification to RSAP" specifically address the inclusion of RSAP within this research project. As discussed in the research proposal, the current NCHRP 22-27 project to Update RSAP has made significant advancements toward using CMFs within RSAP. The development of CMFs which better quantify the roadside environment and the reasons for roadside encroachment will serve to benefit both the crash-based approach (i.e., HSM) to predicting crashes and the encroachment-based approach (i.e., RSAP) and will accomplish the tasks of this research project.

2. The plan outlined in the proposal primarily relies on the use of existing databases. If the existing data proves to be insufficient, how do you propose to collect additional data?

   This is not entirely true; the research team includes the Virginia Tech team that is currently performing NCHRP 17-43. Project 17-43 is mainly a data collection effort for roadside crashes. The goal of NCHRP 17-43 "Long-Term Roadside Crash Data Collection Program" is to develop a continuous sustainable program of in-depth crash data collection as a data-driven approach to investigate the problem of road departure *crashes. The research plan is to conduct in-depth investigation, reconstruction, and analysis of over 1000 road departure crashes which occur over a 48 month period. The first phase of NCHRP 17-43 is now underway in which the data collection protocol is being developed. Should additional data elements be needed for the development of CMFs under the proposed NCHRP 17-54, the timing is ideal to consider these data elements for inclusion in the upcoming field investigations. This coordination will be facilitated by the fact that NCHRP 17-43 is being conducted by Virginia Tech which is also a member of this proposed research team.We hope and expect that this project can provide some insight and suggestions to the 17-43 project for their data collection such that this project (17-54) can obtain some new data as well as look at existing data. That said, however, we expect that we will certainly find areas where the data available and the data that can reasonably be collected in project 17-43 still do not completely answer some questions. We will make recommendations for further data collection specific CMF development along with the priority of that data element.*

3. Although freeways are not specifically mentioned in the Research Project Statement, the panel believes, that if feasible, that the development of freeway roadside CMFs should be considered. However, contact should be made with the Principal Investigator on NCHRP Project 17-45, "Enhanced Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges" to avoid any duplication of effort.

   The research team presumed that the exclusion of freeways was intentional on the panel's part. Also, there are some statistical modeling issues related to freeways. Fortunately, the construction of the interstate highway system and the publication of the 1977 Barrier Guide essentially coincided with each other. The vast majority of interstates conform to what was the governing roadside design practice and what has evolved into the Roadside Design Guide (i.e., 1977 Barrier Guide). Finding data for the specific analysis of freeway roadsides which do not conform to the RDG or the 77 Barrier Guide would prove challenging, however, there certainty are unique cases littering the county particularly on interstate ramping systems. In short, there is not as much variation on roadside design on the freeway system so it may be difficult to get very strong statistical relationships on freeway data. The research team, however, is certainly willing to include freeways if the panel so desires and we would certainly be interested in coordinating with the Project 17-45 research team.

4. Please provide a more legible copy of the Virginia Tech budget.

   A more legible copy of the Virginia Tech budget is provided at the end of this document.

5. Please provide additional clarification on the “Equipment and Facilities” section of your proposal.

The proposal states that “this project will not require any specialized facilities or equipment beyond typical office computers. The project team members have all necessary computers and software to perform the project.” If data collection is required it will be performed by the Project 17-43 team and they use NASS PSU data collectors for data collection. The project team members have vast highway and roadside safety libraries at their disposal for this project and all necessary computer hardware and software.

PRIN. INVESTIGATOR: Clay Gabler
BUDGET PERIOD: 2/1/11 through 1/31/13
DUE DATE:

		02/01/11-01/31/12 Year 1			02/01/12-01/31/13 YEAR 2			TOTAL
	NAME/POSITION	% EFFORT	REQUESTED SALARY	FRINGES	% EFFORT	REQUESTED SALARY	FRINGES	REQUESTED SALARY
1	Clay Gabler (1 SMR month)	12%	$17,015	$4,722	12%	$17,696	$4,911	$34,711
2	GRA (Step 15)	50%	$11,222	$786	50%	$11,559	$809	$22,781
	TOTAL PERSONNEL SALARIES		$28,237			$29,255		$57,492
	FRINGE BENEFITS: See rates below		$5,508			$5,720		$11,228
	TOTAL SALARIES AND FRINGES		$33,745			$34,975		$68,720
	TUITION & ACADEMIC FEES - AY		$5,338			$5,818		$11,156
	TRAVEL		$2,500			$2,500		$5,000
	Domestic	$2,500			$2,500			
	TOTAL DIRECT COSTS		$41,583			$43,293		$84,876
	INDIRECT COSTS-On Campus Research. Federal Rate		$9,895			$10,229		$20,124
	Negotiated Rate through Project End, MTDC 27.3% 27.3%	$9,895			$10,231			
	TOTAL COSTS		$51,478			$53,522		$105,000
	Base for Indirect Costs		*$36,245*			*$37,475*		

	Through 6/30/10	On or after 7/1/10
Regular Faculty	32.50%	27.75%
Special Research Faculty	35.25%	30.75%
Part Time Faculty	22.50%	17.00%
SMR/WAGES	6.75%	7.50%
GRA	6.50%	7.00%
CLASSIFIED	46.00%	37.75%