A New Approach to Run-off-Road Crash Prediction

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ABSTRACT
The need to operate and maintain roadways and improve roadside safety with limited resources often necessitates incremental improvements over time. Modeling tools that enable roadside designers to estimate the effectiveness of making various safety improvements are essential in making these decisions and balancing trade-offs between efficacy and cost.

Historically, models used to represent the relationships between run off road (ROR) crashes and roadside features have been categorized as into two approaches: crash-based approaches or encroachment-based approaches. The encroachment-based approach has been incorporated in the Roadside Design Guide (RDG) for decades whereas the crash-based approach is used in the Highway Safety Manual (HSM). The current edition of the HSM has very limited utility for considering ROR crashes and counter-measures.

This paper presents a new approach to ROR crash estimation that capitalizes on the strengths of both approaches by combining the understanding of crash events provided by the encroachment probability approach and the assets of the crash-based data to develop this ROR crash prediction method. The ROR crash prediction model structure proposed herein captures assumptions about the way ROR crashes occur and the mechanisms that influence both the frequency and severity of any resulting crashes. The proposed model structure requires minimal additional data collection. The method presented in this paper has been developed for incorporation of the explicit consideration of roadside features in a future edition of the HSM. This method is suitable for use by those wishing to develop jurisdiction-specific models.
INTRODUCTION
Highway engineers are constantly redesigning and rebuilding roadways to meet higher standards, provide safer highways and increase mobility. For the last thirty years this has included designing and building roadways that are more forgiving when a driver inadvertently encroaches onto the roadside. There are, however, many impediments that keep highway designers from achieving the desired design and operational goals of safety and mobility including the need to operate, maintain, and improve a vast highway system with limited resources. Consequently, highway engineers are often required to make incremental improvements over time and make difficult trade-offs between cost, safety and mobility. Modeling tools that enable highway engineers to quantify the effectiveness of making specific safety improvements are essential in making these decisions and balancing the trade-offs.

Historically, models used in to represent the relationships between run off road (ROR) crashes and roadside features such as utility poles, traffic sign posts, trees, guardrail, median barriers, etc. have been categorized as either crash-based or encroachment-based approaches. The encroachment-based approach is incorporated in the Roadside Design Guide (RDG) whereas the crash-based approach is used in the Highway Safety Manual (HSM). (1, 2) Both approaches have their strengths and weaknesses.

This paper presents a new approach to ROR crash prediction that combines the theories of both the encroachment probability approach and the crash-based approach to develop ROR crash prediction methods. The method presented in this paper has been developed for incorporation of the explicit consideration of roadside features in the HSM. This method is suitable for use by those wishing to develop jurisdiction-specific models.

BACKGROUND

Encroachment Approach
There is a long history of the use of the encroachment-based approach for cost-benefit and probabilistic modeling in roadside safety dating back to at least 1974. Ross included Glennon’s basic risk-based cost-benefit procedure for roadside safety in Chapter VII and Appendix E of the 1977 Barrier Guide, the first document promoted by the American Association of State Highway and Transportation Officials (AASHTO) that provided guidance on designing the roadside. (3, 4) In 1988, AASHTO revised the 1977 Barrier Guide transforming it into the Roadside Design Guide. (5) Appendix A of the Roadside Design Guide included a revision of the cost-effectiveness procedures and provided a computer program called ROADSIDE to ease the calculation burden on designers and policy makers. Research and technology advancements prompted the development of the Roadside Safety Analysis Program (RSAP) which was completed in 2003 and documented in NCHRP Report 492. (6) The third version of RSAP (RSAPv3) was released in 2012. (7) The encroachment probability model, as supported these software packages, has been a feature of each edition of the Roadside Design Guide since 1988. (5, 8, 9, 1)

The encroachment-based approach divides the encroachment event into a series of sub-events; from vehicle departure from the travel lanes, to its path across the roadside, to any possible collision and the subsequent severity of the crash. The encroachment probability model is built on a series of conditional probabilities. First, the probability that a vehicle will encroach on the roadside (or median) is calculated. Second, given an encroachment has occurred, the crash prediction module assesses the probability that the encroachment would result in a crash,
$P(C|E)$. If a crash is predicted, the severity prediction module estimates the severity of the crash, $P(I|C)$. The risk of observing a crash of particular severity and/or the cost-benefit analysis is conducted last to select the most cost-effective alternative.

The advantages to this approach include the ability to consider very detailed design alternatives for which crash data are not likely to be available or for which data may be too expensive to collect. Roadside inventories have traditionally lagged behind other highway inventory data. Further, as roadside hardware advancements are made (e.g., updating from 27 inch to 31 inch w-beam), observed data is often not available to support the updating of roadside policy using a crash-based approach. The encroachment probability model, as coded in RSAPv3, was developed to support these situations. These same features present one disadvantage to the encroachment-based approach; the accuracy of the predictions are not always verifiable.

**Crash-Based Approach**

Crash-data based approaches take advantage of police-level crash reports that are collected by all the States. The main strength of using the crash-based approach is the sheer size of the available crash and road inventory data which are collected and maintained routinely by state Departments of Transportation (DOT's) and Departments of Public Safety. The limitation of using this real-world crash data is its lack of detail regarding the roadside hardware (e.g., unknown barrier height), vehicle, and collision conditions (e.g., impact speed). In addition, minor crashes tend to be underreported in the state traffic crash database so this approach is likely biased toward higher severity crashes.

In the last four decades there have been and continue to be dramatic advancements in the statistical and biomedical sciences on specialized statistical regression methods for handling discrete/categorical types of response data, such as event frequency or event count data like highway crashes. The promising results from many of these studies over the past several years have led to developing a Highway Safety Manual (HSM). (2)

Run-off-road (ROR) crashes were just a small portion of the crashes of interest in all the HSM projects and unfortunately were not modeled specifically in any of the first edition HSM chapters. (2) Total crashes were modeled and ROR crashes are found by applying a multiplier for two-lane highways. This multiplier assumes ROR crashes are linearly related to traffic volume. This assumption is not consistent with research presented in the Roadside Design Guide. (1) Other chapters mix single vehicle crashes with ROR crashes. This decision mixes animal, pedestrian, ROR, and other types of single vehicle crashes while not accounting for the multiple vehicles crashes which result in vehicles leaving the road. The treatment of ROR crashes in the first edition of the HSM, therefore, was not particularly useful.

The advantage to the crash-based approach is that statistically robust models can be developed using large datasets and these robust models can be subjected to rigorous quality control to provide users great confidence in the results. Many States are just now starting to gather barrier inventories and continue to lack inventories of other hardware, slopes, and narrow fixed objects such as trees and poles. These new inventories will provide another source of supplemental data that can be integrated into statistical model building in the future. Model development, however, is limited to situations which are observable. Unreported crashes (i.e., roadside safety success) are not observable. Designs that are just starting to be implemented in the field are not observable. Complex roadsides with multiple features are generally not observable.
Summary

The crash-based approach can be used to leverage course details (e.g., amount of barrier) and conduct corridor planning studies. The encroachment-based approach is best suited for examining very detailed design scenarios. An approach which can leverage the large datasets of observable crash data and the theory of how ROR crashes occur is needed to provide both confidence in the results and the ability to model detailed design alternatives.

ENTITY OF CONCERN

The characteristics of the roadside differ within each segment and often differ between each edge of the segment (e.g., there may be guardrails on the right hand side of the road protecting a foreslope and an unshielded backslope on the left). The entity of concern for the analysis of ROR crashes should therefore understandably be each roadside edge. The first edition of the HSM considers segments and intersections as the entity of concern, which is appropriate for modeling on-road crashes and intersection crashes. Segments in an HSM context are portions of roadways which share all the same characteristics. Segments alone are insufficient to model ROR crashes since the roadside characteristics are changing continually along any typical roadway segment.

Figure 10-2 of the first edition of the HSM (2) graphically depicts the segment length and intersection definitions using the letters “A” and “B” for homogeneous segments and intersections respectively. Incorporation of roadside edges requires only a minor modification to this figure, as shown in Figure 1. The letter “C” has been added to show the user that segment edges should also be considered as an entity of concern for ROR crashes.

Figure 1 Entity of Concern Graphically Depicted
Run-Off-Road Crash Prediction General Form

Equation 1 shows a very general form of an ROR crash prediction model. The model predicts the number of expected crashes in a year of a particular severity that cross a particular edge of a particular roadway segment.

\[ N_{\text{SEVERITY}} = SPF_{\text{EDGE}} \cdot CMF_{\text{ROADWAY}} \cdot CMF_{\text{ROADSIDE|SEVERITY}} \] (1)

where:
- \( N_{\text{SEVERITY}} \): Annual number of ROR crashes of a given severity associated with a given roadway segment edge.
- \( SPF_{\text{EDGE}} \): Safety performance function for an edge of the roadway in crashes per mile of segment edge.
- \( CMF_{\text{ROADWAY}} \): A crash modification function that adjusts for the alignment and cross-sectional features of the roadway like grade, curvature, lane width and number of lanes.
- \( CMF_{\text{ROADSIDE}} \): A crash modification function that adjusts for the features of the roadside. Particular crash modification factors used within the roadside CMF are chosen for each level of crash severity.

SPF\(_{\text{EDGE}}\) and CMF\(_{\text{ROADWAY}}\)

The development of SPF\(_{\text{EDGE}}\) and the CMF\(_{\text{ROADWAY}}\) can occur at an individual state level. A multi-state approach is said to improve transferability, however, a single state approach may improve relevance within each state. These two components of the ROR crash prediction model can be developed without any of knowledge of the jurisdiction’s roadside inventory. These two components of the ROR crash prediction model quantify how many ROR crashes are expected by roadside edge and which on-road features (e.g., curvature, grade, lane width, etc.) effect the increase or decrease in ROR crash frequency.

Database Development for Modeling

The compilation of the database for model development merges many techniques from both the crash-data and the encroachment probability approaches. While crashes and encroachments are different in definition, the nomenclature has been adopted here to eliminate any possible conflicts and to provide consistency.

Undivided roadways have a two edges (i.e., right and left edge). Divided roadways have four edges (i.e., outside right and left edges and median right and left edges). Many roadside safety publications reference a primary and opposing direction of travel and the possible vehicle encroachment directions from these directions of travel (i.e., primary right, primary left, opposing right, opposing left). The direction chosen to be the primary direction is arbitrary, but is often considered to be the northerly or easterly direction, the increasing-station direction, or the increasing-milepost direction. The opposing direction is simply the opposite of the primary. Figure 2 shows these possible crash directions graphically.
The first event in the sequence of events where the vehicle exited the roadway is used to determine which edge the vehicle exited the roadway for the purpose of database development. In other words, if a vehicle was traveling north and left the right side of the road, then over corrected and crossed the centerline to exit the left side of the road, the vehicle was counted as a primary right (PR) crash because it was traveling north and first exited the road to the right. Another example would be if a vehicle traveling south entered the median then crossed through the median and became involved in a head-on collision in the north-bound lanes. This would be an opposing left (OL) crash since the vehicle was traveling in the southerly direction and first exited the road to the left. If the direction of crash could not be determined, it should not be excluded, but rather included in the dataset as unknown (UNK).

Ultimately, the models developed need only consider one edge for undivided roadways (PR) and two for divided roadways (i.e., PR and PL). Opposing direction segment edges and crashes should be transformed to primary direction segment edges and crashes after the crashes have been merged with the segment edges. The transformation is simple. For divided roadways: all opposing direction curve and grade signs’ should be reversed and the crashes found to have occurred on the OR or OL edges should be changed to PR and PL edges so that the data can be merged. For undivided roadways: (1) the PR and OL crashes are modeled on the right edge; (2) the OR and PL crashes and the corresponding roadside data can be reversed to allow for merging with the PR and OL crashes. This significant difference represents the difference in undivided and divided roadways. An undivided roadway may have a primary direction right edge crash or a vehicle may cross over the centerline and exit the same right edge. This vehicle which crosses over the centerline has different highway geometrics which affects the probability of departure, however, for simplicity of this method, these cross-over vehicles have been included in the total
edge crashes. Head-on collisions are not an objective of this model because they do not occur on the roadside.

**Model Development**

Development of the models for SPF\textsubscript{EDGE} and CMF\textsubscript{ROADWAY} can progress using methods well documented in the HSM literature for representing crash frequency (e.g., negative binomial regression). Recall that the entity of concern is the roadside edge. A model should be developed for the primary right edge of the undivided roads. Two models should be developed for divided roads: the primary right edge and primary left edge. These models can then be applied by the end user with respect to the direction of travel (e.g., primary right edge and opposing right edge) due to the way the database was developed.

SPF\textsubscript{EDGE} and CMF\textsubscript{ROADWAY} can now be accomplished for both undivided and divided roadways. The results of this modeling effort will be the annual frequency of ROR crashes by edge mile and on-road highway geometric modifiers of that frequency. It is suggested that the first step include modeling the entire dataset including the UNK direction of departure crashes then proportioning the results using models developed for each edge. This approach assumes that UNK departure direction is distributed by the proportion of known coded departure directions. One can then predict the expected number of ROR crashes for each departure direction. Geometric variables in the dataset (e.g., curve, grade, lane width, number of lanes, etc.) can be used to assess the effect of each variables on ROR crash frequency. The selection of appropriate variables for inclusion in jurisdictional models requires individual evaluation and may include a review of the correlation matrix and visual assessment. Recall the undivided roadway model is proposed to include vehicles which cross-over the centerline and exit the roadway to the left. It was found that a second AADT term was needed to help capture these left exiting vehicles. Sample model forms are shown here:

\[
SPF_{\text{EDGE}} = (365 \cdot \text{AADT} \cdot L)^{A_1} \cdot e^{A_2 \cdot \text{AADT}/1000} \cdot e^{A_3}
\]

\[
CMF_{\text{ROADWAY}} = CMF_{\text{LW}} \cdot CMF_{\text{SW}} \cdot CMF_{\text{NL}} \cdot CMF_{\text{PT}} \cdot CMF_{\text{DOC}} \cdot CMF_{\text{G}}
\]

where:

- \(A_n\) = Regression coefficients.
- AADT = Average annual daily traffic (vehicles/day).
- L = Segment centerline length (miles).
- CMF\textsubscript{LW} = Crash Modification Factor for lane width,
- CMF\textsubscript{SW} = Crash Modification Factor for Right shoulder width,
- CMF\textsubscript{NL} = Crash Modification Factor for Number of Lanes,
- CMF\textsubscript{PT} = Crash Modification Factor for Heavy Vehicles,
- CMF\textsubscript{DOC} = Crash Modification Function for Degree of Curvature and
- CMF\textsubscript{G} = Crash Modification Function for Vertical Grade.

**CMF\text{ROADSIDE}**

The encroachment-based approach uses a conditional probability because it has long been recognized that the severity of any roadside crash is dependent on the roadside features involved, not the volume of traffic or length of the segment (i.e., the severity of a crash given a crash occurs). While State-maintained barrier inventories are becoming more prevalent roadside
inventories remain limited at present. As more inventories are collected, however, they will be very useful in the ROR crash prediction process. This ROR crash-based model uses a modified conditional probability approach to leverage the available barrier inventories.

ROR crash type definitions were developed to represent the major categories of ROR crash events. Modeling of CMF_{ROADSIDE} uses the same crash database discussed above, but divides the dataset into crashes with longitudinal barriers (LB) and other crashes (OC). A longitudinal barrier crash is defined as any crash where the longitudinal barrier is the first object struck off the road. In other words, if a vehicle runs off the road to the left and hits a w-beam guardrail, it is a LB crash. If a vehicle side-swipes another vehicle then runs off the road and hits a bridge railing it is also a LB. On the other hand, if a vehicle runs off the road to the right and hits a tree then a longitudinal barrier, it is an OC crash.

Using these definitions for longitudinal barrier crashes (LB) and other crashes (OC), the P(LB) and P(OC) are taken to be mutually exclusive events, \( P(LB \cup OC) = P(LB) + P(OC) \).

This proposed crash-based approach to modeling ROR crashes, therefore, explicitly separates LB and OC crashes. The reason for this is that if fixed objects, slopes and other roadside features are shielded by longitudinal barriers, there is obviously a much lower probability of striking these other features. Countermeasures which may impact the proportion of longitudinal barrier crashes (CMF_{j}) (e.g., barrier offset, barrier type, etc.) or the proportion of other crashes (CMF_{k}) (e.g., narrow fixed object density, offset, terrain, etc.) can now be applied to the correct portion of the function. The roadside crash modification function, CMF_{ROADSIDE}, takes the following form:

\[
CMF_{ROADSIDE} = \left[ \beta_{SHLD} \cdot X_{SHLD} \cdot \prod_{j=1}^{m1} CMF_j \right] + \left[ \beta_{UNSHLD} \cdot X_{UNSHLD} \cdot \prod_{k=1}^{m2} CMF_k \right]
\]

Where:

- \( X_{SHLD} \) = Proportion of the segment edge where longitudinal barriers are installed where \( 0 \leq X_{SHLD} \leq 1 \).
- \( X_{UNSHLD} \) = Proportion of the segment edge where there are unshielded ditches, roadside slopes or other unshielded fixed objects where \( 0 \leq X_{UNSHLD} \leq 1 \).
- Condition that: \( 1 = X_{SHLD} + X_{UNSHLD} \) (100% of the segment edge is accounted for).

- \( \beta_{SHLD} \) = A regression coefficient associated with the segment edges where longitudinal barriers are installed.
- \( \beta_{UNSHLD} \) = A regression coefficient associated with the segment edges where there are unshielded ditches, roadside slopes or fixed objects like trees, tree lines, utility poles, bridge piers, etc.
- \( CMF_j \) = Crash modification factors associated with roadside feature \( j \) that modify the ROR crashes associated with longitudinal barriers. These CMFs would account for characteristics like barrier type, barrier terminals, barrier transitions, barrier offset, etc.
- \( CMF_k \) = Crash modification factors associated with roadside feature \( k \) that modify the ROR crashes associated with unshielded roadsides. These CMFs would account for characteristics like the presence of ditches, the density of narrow fixed objects, and other unshielded objects.
CMF\textsubscript{ROADSIDE} is an additive form since the percent of shielded and unshielded edges (i.e., X\textsubscript{SHLD} and X\textsubscript{UNSHLD}) must sum to one in order to account for the entire segment edge.

**Modeling Methods**

The development of the CMF\textsubscript{ROADSIDE} proceeds where P(LB) is assumed to be a function of the percent of shielding on the segment (X\textsubscript{SHLD}) and can be found using the log odds of the probability (P). The odds of an event occurring are simply the probability of an event (P) occurring divided by the probability of the event not occurring (1-P). \textit{(10)}

\[ \text{Odds} = \frac{P}{1 - P} \]

The limited range of probability (i.e., 0 to 1) present a problem when used directly to find the regression coefficients, therefore, the odds, \[ \frac{P}{1 - P} \], are used instead. For example, if the probability of snow in November is 0.25, the odds of having snow in November are \[ \frac{0.25}{1 - 0.25} = 0.3333 = \frac{1}{3} \]. A person gambling on snow in November would say there is a 1 in 3 chance it will snow in November or a 3 to 1 chance it will not snow in November.

Using the definitions for ROR, LB, and OC, the relationships used to determine CMF\textsubscript{ROADSIDE} can be written as follows:

\[
\begin{align*}
\text{LB+OC=ROR} & = \text{Total ROR crashes per edge are equal to all LB crashes plus all other ROR crashes.} \\
\frac{\text{LB}}{\text{ROR-LB}} & = \text{Odds of a longitudinal barrier crash to all ROR crashes.} \\
\frac{\text{OC}}{\text{ROR-OC}} & = \text{Odds of a non-longitudinal barrier crash (i.e., other crash) to all ROR crashes.}
\end{align*}
\]

Simple logistic regression is an appropriate tool when considering one nominal variable with two values (i.e., longitudinal barrier crash, other ROR crash) and one measurement variable (i.e., amount of shielding on the segment). In this case, the nominal variable is the dependent variable and the measurement variable is the independent variable. “One goal is to see whether the probability of getting a particular value of the nominal variable is associated with the measurement variable; the other goal is to predict the probability of getting a particular value of the nominal variable, given the measurement variable.” \textit{(11)}

Log odds provide a more suitable variable for regression modeling using a maximum-likelihood line fit. When \( \beta_{\text{SHLD}} \) is the slope and \( \varepsilon \) is the intercept, the model takes this form and can be rewritten to find the probability, as shown here:

\[
\ln \left( \frac{P(\text{LB})}{1 - P(\text{LB})} \right) = \varepsilon + \beta_{\text{SHLD}}X_{\text{SHLD}}
\]

Applying the same concepts, a series of simple logistic regression models can be used on the same dataset to determine the probability of longitudinal barrier crashes across different severities (i.e., P(LB\textsubscript{SEVi})) and the probability of other ROR crashes across different severities (i.e., P(OC\textsubscript{SEVi})).
Where:

\[
\frac{LB_{\text{severity } i}}{ROR - LB_{\text{severity } i}} = \text{Odds of longitudinal barrier crash of a particular severity to all ROR crashes}
\]

\[
\frac{OC_{\text{severity } i}}{ROR - OC_{\text{severity } i}} = \text{Odds of a non-LB crash (i.e., other crash) of particular severity to all ROR crashes.}
\]

Throughout the derivation of \(\beta_{\text{SHLD}}\) and \(\beta_{\text{UNSHLD}}\), CMF\(_j\) and CMF\(_k\) are taken to be unity since the modelling at this point is based on the mean roadside condition of the base segments.

**Companion CMFs for CMF\(_{\text{ROADSIDE}}\)**

Countermeasures which may impact the frequency or severity of longitudinal barrier crashes (CMF\(_j\)) (e.g., barrier offset, barrier type, etc.) or other crashes (CMF\(_k\)) (e.g., narrow fixed object density, offset, terrain, etc.) can be developed using methods documented in the Federal Highway Administration technical report FHWA-SA-10-032, titled “A Guide to Developing Quality Crash Modification Factors.” (12) These statistical estimations and their associated errors are assumed to account for independent effects of countermeasures, therefore, they can be developed and applied independent of each other. Further, CMFs should be developed from data which is representative of a wide range, not limited to a particular severity or type of location to allow for the CMF to be applicable to the same range of sites.

CMFs, at the most elementary level, can be viewed as a ratio of one treatment to a different treatment. Each CMF estimation method is a different means of developing this ratio. CMFs do not predict the frequency of crashes, but modify the predicted frequency of ROR events estimated by the SPF. CMFs are multipliers.

CMFs can be developed through a before-after study which compares a “before” period to an “after” period. Hauer described this approach to the development of CMFs. (13) This type of approach may be appropriate in roadside application when jurisdiction-wide improvements are made such as reestablishment of a clear zone.

The Empirical Bayes (EB) method is very popular for general highway CMF development, however, it may be limited for the estimating CMF\(_j\) and CMF\(_k\) simply due to a lack of available inventories and perceived lack of knowledge of base conditions. If a jurisdiction has a detailed inventory, this method may be a good choice. It involves estimating the expected number of crashes and comparing it with the observed number of crashes for a particular hazard. The Full Bayes (FB) method and cross-sectional studies have the same road-based data needs as the EB method when applied to estimating the effect of roadside safety improvements.

Case-control and cohort studies compare the relative effect of a treatment to a non-treatment or the relative decrease in severity for any treatment. A case-control study establishes the population of interest from existing crashes, then distinguishes between the cases and controls. The cohort study established a study area and collects cases and controls as the crashes occur. These two estimation approaches are very effective for the development of CMF\(_j\) or CMF\(_k\) because existing knowledge of the roadside inventory is not need and can be collected as part of the study.

After many CMF\(_j\) and CMF\(_k\) have been developed, a meta-analysis or expert panel may be considered, however, there is not any justification for combining CMFs yet, as the quantities to justify this combining effort do not yet exist.

Estimating these CMFs will require collection of roadside feature data. Ideally, this effort should be conducted in the same jurisdiction to allow the mean of this dataset to equal the
mean of the dataset used to establish $\text{CMF}_{\text{ROADSIDE}}$ as represented by $\beta_{\text{SHLD}}$ and $\beta_{\text{UNSHLD}}$. Ideal situations do not always present themselves, however, and one should not be deterred for this reason alone.

**Alternative Approach to Estimating CMF$_j$ and CMF$_k$**

The before-after approach described by Hauer (13) has been adopted, but modified here to propose an alternative method using simulated data. Simulated data is suggested to overcome possible obstacles including lack of detailed roadside inventories, large quantities of roadside objects, or data collection costs. The use of the third version of the Roadside Safety Analysis Program RSAPv3 (7) to simulate crashes before and after treatment will allow jurisdictions to quantify countermeasures where data are not available. When field collected data becomes available, it should be preferred.

**DISCUSSION AND CONCLUSION**

The structure of the ROR crash prediction model captures assumptions about the way ROR crashes occur and the mechanisms that influence the severity of any resulting crashes. For example, the undivided roadway ROR crash frequency has an extra AADT term which drops out of the divided roadway model. This extra term is needed to model the vehicles which may cross the opposing lanes of traffic on undivided roadways to depart the road to the left and those vehicles which may depart the road right to avoid an opposite direction crash.

The process presented herein requires minimal data collection by the states. To perform an assessment; only the geometric data and the percent of longitudinal barrier present is needed to estimate ROR frequency and severity. This proposed process exploits the established encroachment-based approach for the study of ROR crashes while allowing for the use of the vast quantities of crash-based datasets collected by various jurisdictions.

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