Modeling Safety in Utah

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Abstract: In 2010 the American Association of State Highway and Transportation Officials published a new transportation safety guide, the Highway Safety Manual (HSM), to provide transportation professionals with a single authoritative document to aid in estimating safety impacts. State Departments of Transportation (DOTs) have taken a variety of approaches to implement the information presented in the HSM in their states. The Utah Department of Transportation has taken a proactive approach to implementing the HSM. Research has been, and continues to be, conducted to utilize the HSM procedures in the state, while also developing independent analysis methodologies to model safety. The purpose of this paper is to present the methodology for an independent model developed in Utah for highway safety mitigation that utilizes hierarchical Bayesian statistical methods and geographic information system tools to identify hot spot locations and to begin the process of evaluating and identifying mitigating factors to help improve safety statewide. The model incorporates predictive methods of highway safety analysis and allows transportation officials to proactively improve the safety of the transportation system. As state DOTs adopt such a methodology for safety mitigation, and take a proactive approach to implementing safety in their state, they can begin to maximize the benefits resulting from highway safety investment.

INTRODUCTION

In 2010 the American Association of State Highway and Transportation Officials (AASHTO) published a new transportation safety guide, the Highway Safety Manual (HSM), to provide transportation professionals with a single authoritative document to aid in estimating safety impacts (AASHTO 2010). State Departments of Transportation (DOTs) have taken a variety of approaches to implement the information presented in the HSM in their states and to identify the worst (i.e., ‘hot spot’) segments for safety in the state. The Utah Department of Transportation (UDOT) has taken a proactive approach to implementing the HSM to meet the need to identify a systematic approach to address highway safety concerns and to pinpoint critical corridors, or hot spots, for further analysis.

In response to the need to identify a systematic approach to address highway safety concerns and to pinpoint critical corridors in the state, research has been conducted in Utah to utilize and calibrate the HSM procedures in the state (Brimley et al. 2012, Saito et al. 2011, Schultz et al. 2012a), to conduct before and after studies of safety countermeasure effectiveness (Olsen et al. 2011, Schultz et al. 2010, Schultz et al. 2011a), and to develop independent analysis methodologies to model safety (Schultz et al. 2011b, Schultz and Dudley 2012). The purpose of this paper is to present the methodology for an independent model developed in Utah for highway safety mitigation that utilizes hierarchical Bayesian statistical methods and geographic information systems (GIS) tools to identify hot spot locations and to continue the process of evaluating and identifying mitigating factors to help improve safety statewide. The model incorporates predictive methods of highway safety analysis and allows transportation officials to proactively improve the safety of the transportation system. As state DOTs adopt such a methodology for safety mitigation, and take a proactive approach to implementing safety in their state, they can begin to maximize the benefits resulting from highway safety investment.

The results of this research have been published, or are currently under review, in the literature. As a result, this paper will provide a brief summary of the methodology, while providing the reader with the references necessary to obtain full analysis results.

MODEL FRAMEWORK

The methodology developed for UDOT follows the framework for highway safety mitigation summarized in Figure 1 and explained in more detail in the literature (Schultz et al. 2011b, Schultz and Dudley 2012). The general methodology that has been developed and is currently being implemented in Utah includes seven primary steps, each of which can be tied to the framework in Figure 1. The steps include: 1) data collection, 2) statistical model, 3) GIS model, 4) diagnosis, 5) countermeasure selection, 6) economic appraisal and project prioritization, and 7) effectiveness evaluation. The first three steps correspond to the first element of the framework (Identify Safety 'Hot Spots'), the next three steps correspond to the second element of the framework (Implement Cost-Effective Countermeasures), while the final step corresponds to the third element of the framework (Improve Future Decision Making and Policy). Each of the steps will be explained briefly in the following sections.

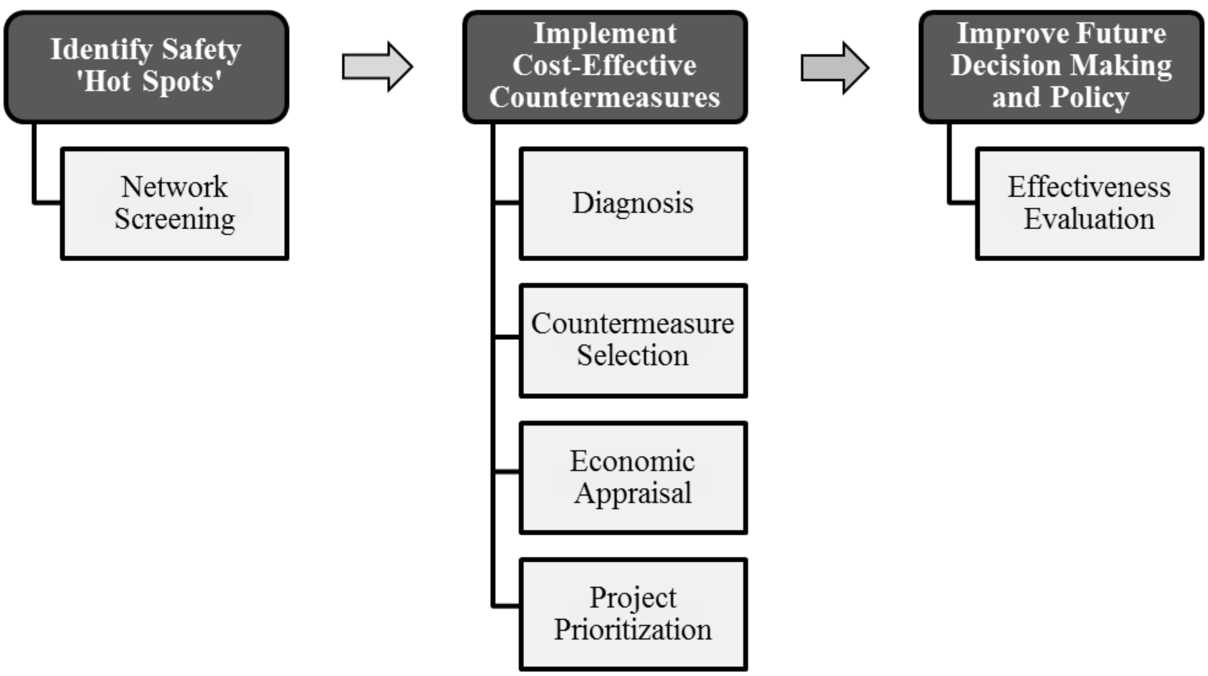

Figure 1. Framework for highway safety mitigation.

Step 1: Data Collection

The first step in the process is to collect data for both roadway segments and crashes.

Roadway Segment Data

Roadway segments are developed based on available attribute data for the network. For the current Utah analysis, roadway segments were developed based on the following attributes: 1) speed limit, 2) number of through lanes, 3) average annual daily traffic (AADT), 4) functional classification, and 5) urban code. At each location where one of the listed attributes changed, a new segment was developed. When developing roadway segments it is important to maintain a balance between preserving attributes for analysis and maintaining segments that are not too short. The attributes utilized resulted in 4,151 segments statewide.

Crash Data

The crash data for Utah were provided by UDOT and include three levels of data: 1) crash, 2) vehicle, and 3) people. The databases are linked together by a common crash ID.

Step 2: Statistical Model

A hierarchical Bayesian model was developed in the R programming language to analyze crashes (RPSC 2012). In a hierarchical Bayesian analysis prior information and all available data (e.g., past history of crashes and roadway data) are integrated into posterior predictive distributions (i.e., future predictions of crashes) from which inferences can be made to account for uncertainties in the analysis. Hierarchical Bayesian methods were utilized to obtain posterior predictive distributions for each parameter in the model and for every segment. Samples from each conditional posterior were obtained using Markov Chain Monte Carlo (MCMC) and Gibbs sampling methods (Gelfand and Smith 1990, Qin et al. 2005). This results in posterior predictive distributions for each segment in the model. It is important to point out that the results of the Bayesian models generate distributions of crashes, rather than simply point estimates. This is useful in the development of percentiles that indicate the likelihood of a crash. More details regarding the model can be found in the literature (Schultz et al. 2012b).

Using the posterior predictive distributions obtained from the hierarchical Bayesian model, predictive distributions were constructed for each segment. Posterior predictive distributions give a distribution of the number of crashes that would be expected on a segment based upon the characteristics in the model. Next, the actual number of crashes were compared to the posterior predictive distribution to determine where the actual numbers of crashes fall with respect to the distribution by observing the area to the left of the actual number of crashes in the posterior predictive distribution, or the percentile of the actual number of crashes (between zero and one). A high percentile (near one) indicates that the actual number of crashes is larger than predicted on that segment, while a percentile near zero indicates that the segment had fewer crashes than predicted (Schultz et al. 2012b).

An example posterior predictive distribution produced by the model is shown in Figure 2. The bars represent the distribution of the number of crashes that would be expected on this segment based on analysis of all segments with similar characteristics. The solid vertical line represents the actual number of crashes for this segment. The proportion of the area of the distribution to the left of the solid vertical line is the percentile (approximately 0.72 here) (Schultz et al. 2012b).

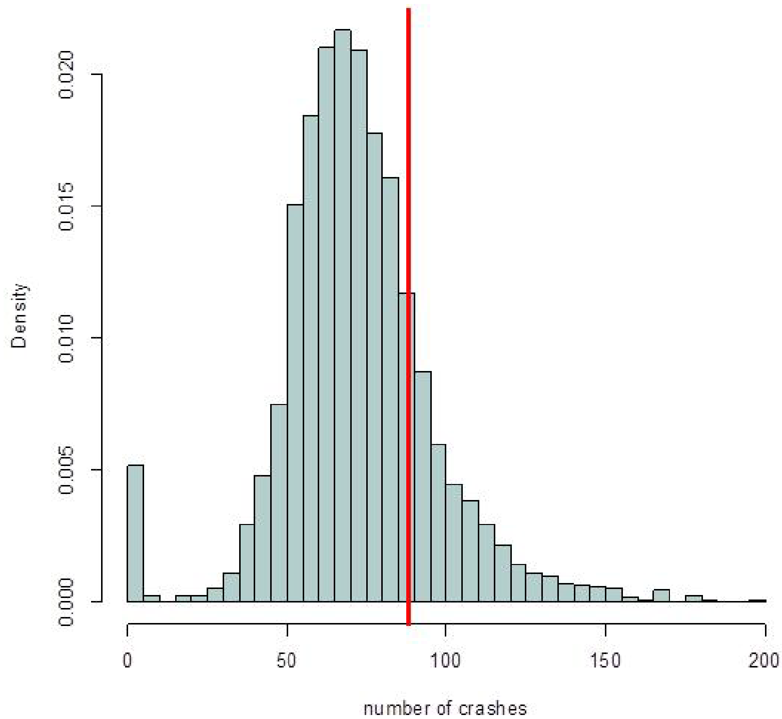

Figure 2. Example posterior predictive distribution and actual crashes (solid line).

Step 3: GIS Model

GIS tools have been shown in the literature to be an effective safety analysis tool (Graettinger et al. 2005, Harkey 1999, Li and Zhang 2007, Miller 1999, Mitra 2009, Qin and Wellner 2011, Roche 2000). As such the next step in the analysis was to visually display the results of the statistical model to help pinpoint the locations where the number of actual crashes are larger than the number of predicted crashes. In this process, the results of the statistical model are imported to ArcMap and the segments are mapped using the state linear referencing system. The results are then displayed using a color scale that corresponds to the percentile (i.e., crash risk) outlined in Step 2. Results of the analysis are color coded to help pinpoint hot spot segments. Details on the overall GIS model framework can be found in the literature (Schultz et al. 2012b).

An example of the output from the model is shown in Figure 3 for the state of Utah (note that this figure is for illustration purposes only and does not represent final analysis results for the state). The percentile ranks for the color-coding were selected so that 5 percent of the segments would fall in the highest and lowest groups (red and blue respectively), 15 percent of segments would fall in the next highest and lowest groups (orange and green respectively), and 60 percent of segments would fall in the middle range (light green). These percentiles can be adjusted based on user preference (Schultz et al. 2012b).

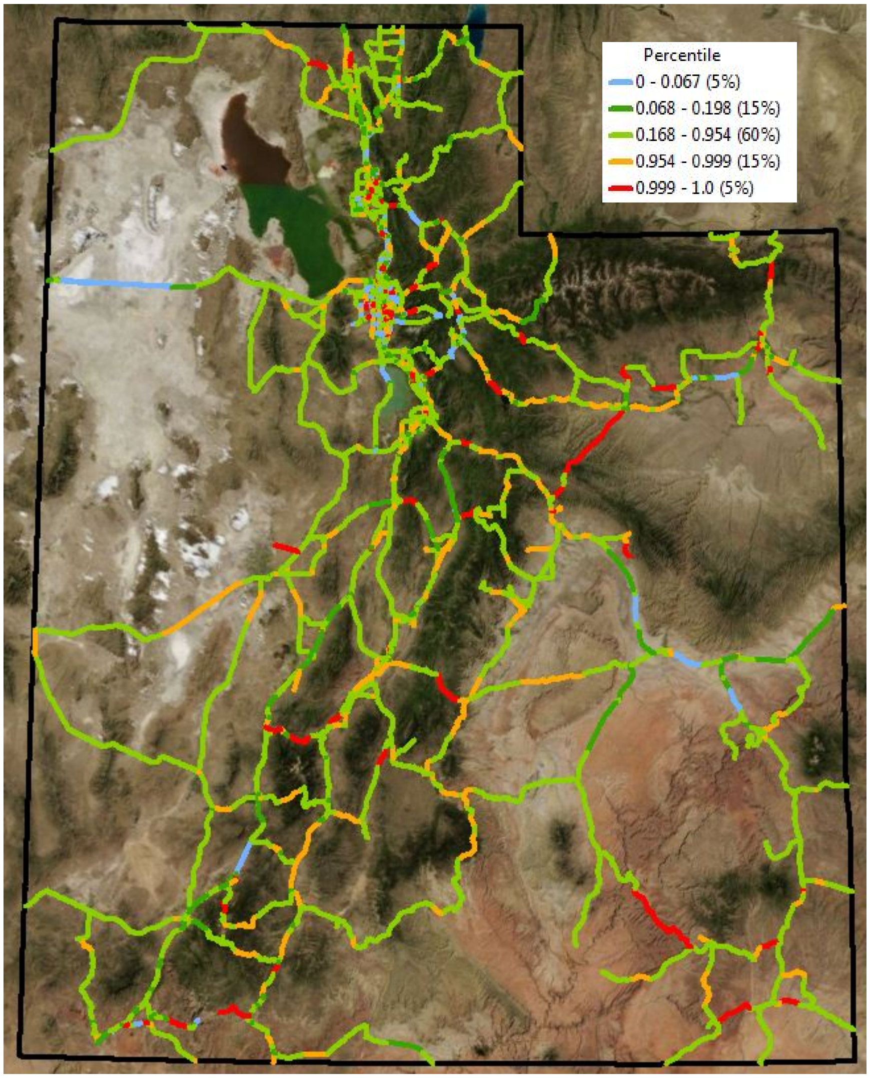

Figure 3. Statewide model results displayed by percentile.

Step 4: Diagnosis

The diagnosis step is an ongoing step in the analysis. In this step, advanced GIS tools such as spot analysis, strip analysis, and sliding scale analysis are utilized to evaluate each segment that was identified as a hot spot in the analysis to evaluate the segment and pinpoint crash clusters (Esri 2013). This step is used to better be able to identify appropriate countermeasures for analysis.

Step 5: Countermeasure Selection

The countermeasure selection process is currently (as of April 2013) underway in the state. In this step, hot spot segments and clusters identified in the previous steps are evaluated to identify common characteristics of crashes and to recommend countermeasures that will aid in addressing the problem using the National Cooperative Highway Research Program (NCHRP) 500 Series reports as a starting point. Once specific countermeasures are identified, they will be recommended for each hot spot for implementation and analysis.

Step 6: Economic Appraisal and Project Prioritization

With countermeasures identified in step 5, this step is used to prioritize the projects identified to aid UDOT in allocating funds. This step in the analysis is currently ongoing and will include detailed benefit/cost (B/C) analyses based on the effectiveness of the chosen countermeasures.

Step 7: Effectiveness Evaluation

This step is an ongoing process to evaluate the countermeasures once they are implemented. This step includes tracking of progress and performance of before/after studies to determine the effectiveness of the countermeasures that can then be considered in future analyses. The primary output from this step is the development of crash modification factors (CMFs) for the countermeasures. Several examples of effectiveness evaluation that have been performed in Utah can be found in the literature (Olsen et al. 2011, Schultz et al. 2010, Schultz et al. 2011a).

CONCLUSIONS

State DOTs have taken a variety of approaches to implement the information presented in the HSM in their states and to identify the worst (i.e., 'hot spot') segments for safety. UDOT has taken a proactive approach to implementing the HSM and to meet the need to identify a systematic approach to address highway safety concerns and to pinpoint critical corridors or hot spots for further analysis.

The purpose of this paper was to present the methodology for an independent model developed in Utah for highway safety mitigation that utilizes hierarchical Bayesian statistical methods and GIS tools to identify hot spot locations and to continue the process of evaluating and identifying mitigating factors to help improve safety statewide. The methodology developed for UDOT follows the framework for highway safety mitigation outlined in the HSM and adapted for use in the state. The general methodology that has been developed and is currently being implemented in Utah includes seven primary steps, each of which can be tied to the framework for highway safety mitigation. The steps include: 1) data collection, 2) statistical model, 3) GIS model, 4) diagnosis, 5) countermeasure selection, 6) economic appraisal and project prioritization, and 7) effectiveness evaluation. The first three steps correspond to the first element of the framework (Identify Safety 'Hot Spots'), the next three steps correspond to the second element of the framework (Implement Cost-Effective Countermeasures), while the final step corresponds to the third element of the framework (Improve Future Decision Making and Policy).

As state DOTs adopt similar methodologies for safety mitigation, and take a proactive approach to implementing safety in their state, the benefits resulting from highway safety investment will be realized in fewer crashes and fewer fatalities on the roadway.

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