Modeling Safety in Utah

2013 Western District Annual Meeting

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Session 3D

1:30 – 3:00 p.m.

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Outline

- Introduction
- Model Framework
- Conclusions

Introduction

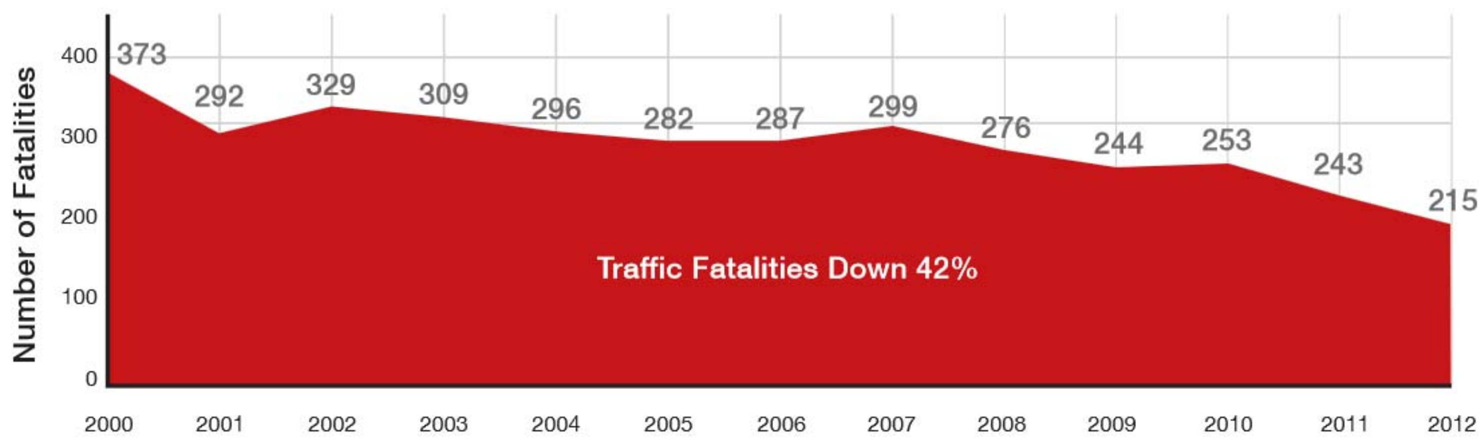
- Need for integration of safety
- Utah highway safety statistics
- Highway Safety Manual (HSM)
- Fundamentals of safety analysis

Need for Integration of Safety

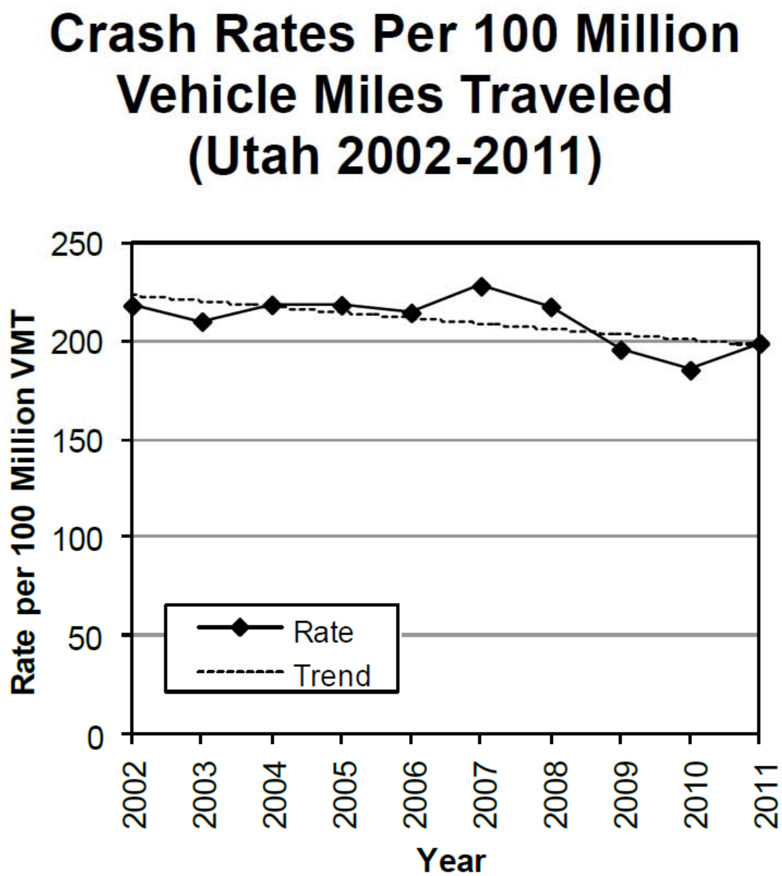
- Safety has long been an important consideration in transportation decision making
- SAFETEA-LU (2005):
  – Highway Safety Improvement Program (HSIP) seeks to reduce the number of fatal and injury crashes through state-level engineering methods
- Decision makers need good methods and tools to make optimal decisions to improve safety

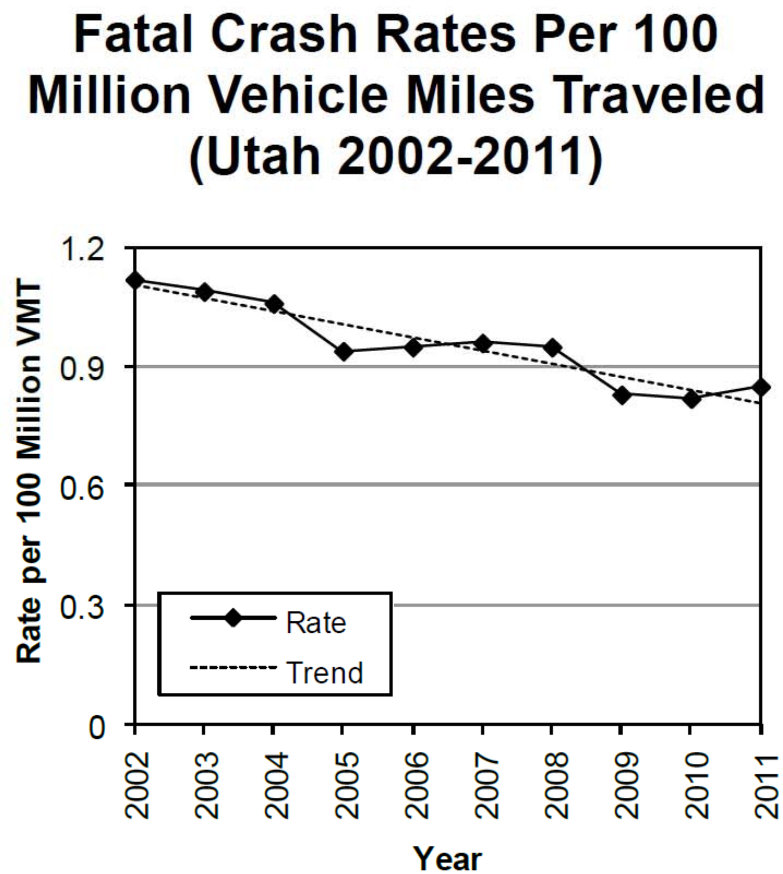
Utah Highway Safety Statistics

- Total reported crashes: 53,368 (2002)
- Total reported crashes: 49,368 (2010)
- Total reported crashes: 52,287 (2011)



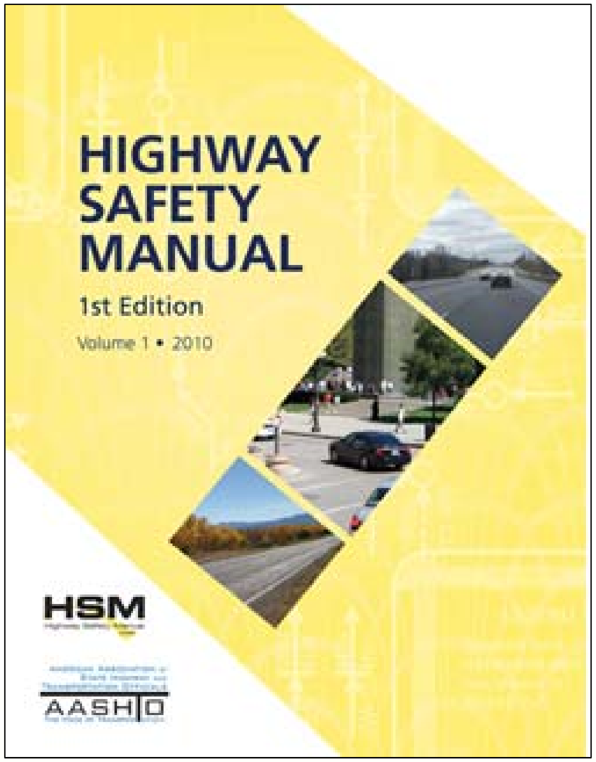
Utah Highway Safety Statistics





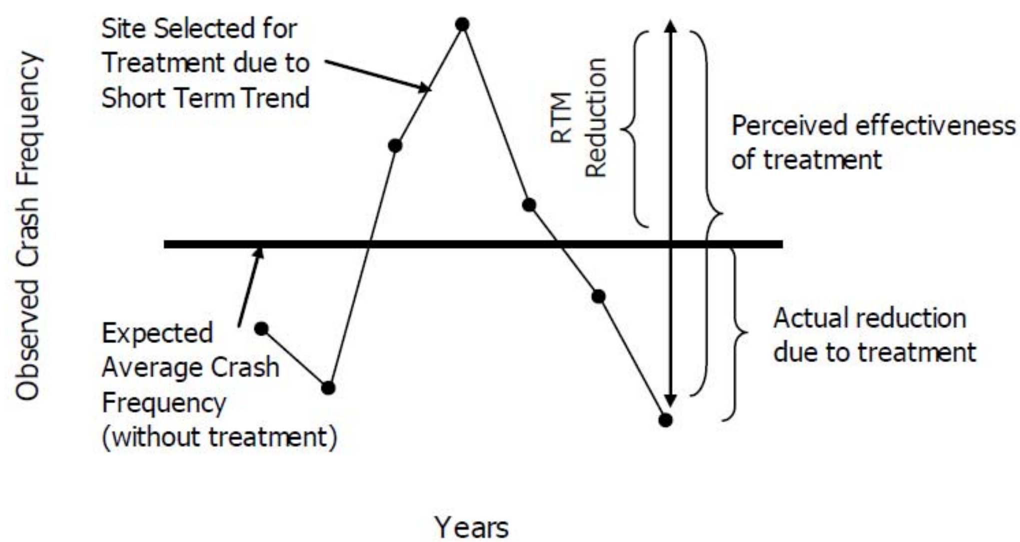
Highway Safety Manual (HSM)

- Published in 2010 by AASHTO
- Purpose:
  - Integrates safety into the decision-making processes
  - Science-based
  - Provides information and tools
- No legal obligation
- Updated with recent research



Fundamentals of Safety Analysis

- Crash data limitations:
  - Randomness and change
  - Regression to the mean (RTM) bias



Fundamentals of Safety Analysis

- Descriptive analysis:
  - Based on historical crash data
  - Traditional methods:
    - Crash Rate = # of crashes / exposure
    - Crash Frequency = # of crashes / period of years
  - Fails to account for RTM

Fundamentals of Safety Analysis

- Predictive analysis:
  - Crash Prediction:
    - Safety Performance Function (SPF):
      - N_{spf} = (AADT) X (L) X (365) X (10^{-6}) X ($e^{-0.312}$)
    - Crash Modification Factor (CMF):
      - CMF = Crashes condition A / Crashes condition B

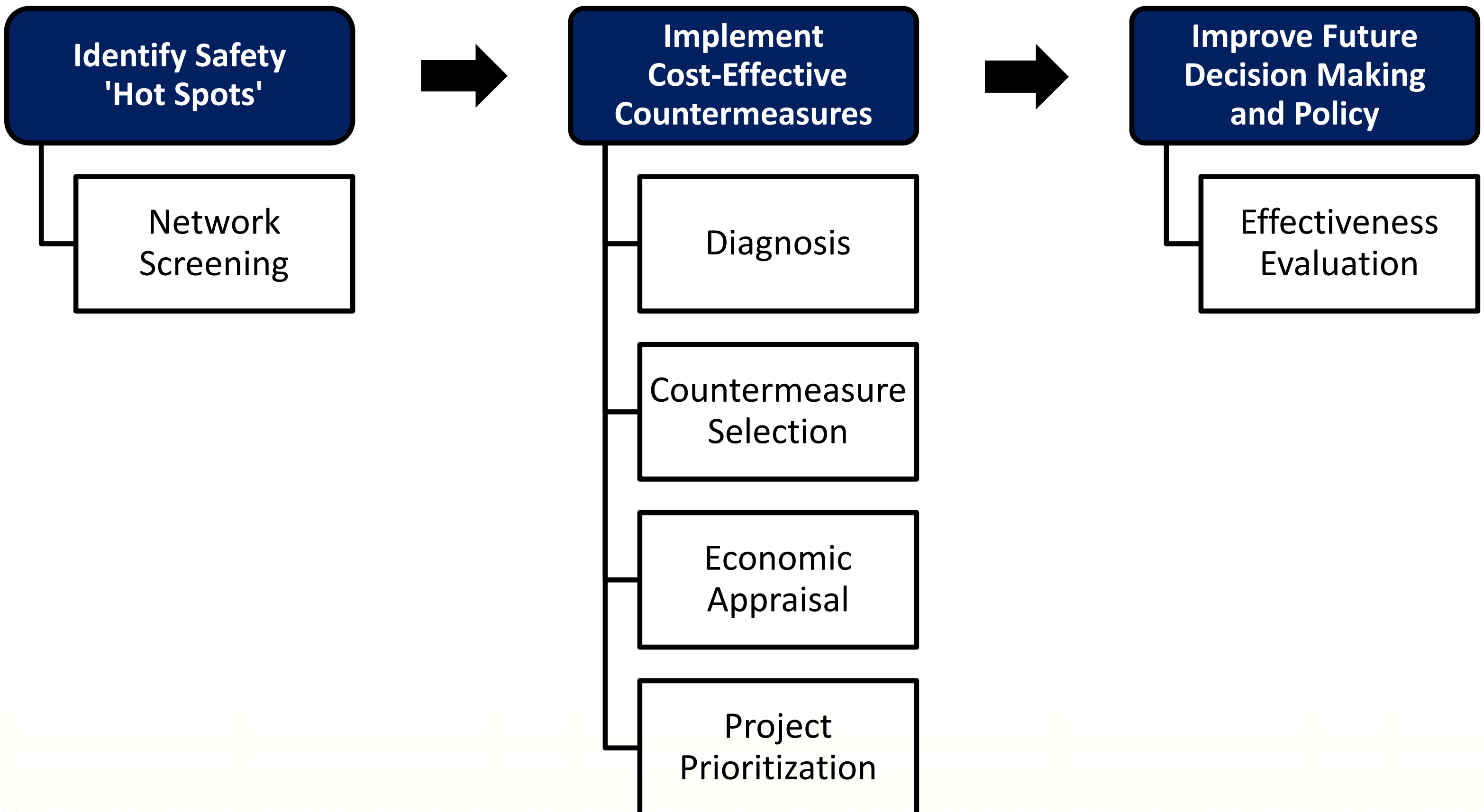
Fundamentals of Safety Analysis

- Predictive analysis:
  - Statistical Methods:
    - Empirical Bayes Method
    - Hierarchical Bayes Method
  - Bayesian methods use:
    - Prior knowledge – history of similar sites
    - Likelihood of certain events
    - Bayes theorem for degree of uncertainty

Model Framework

- HSM safety mitigation framework
- Utah safety mitigation framework

HSM Safety Mitigation Framework



Utah Safety Mitigation Framework

- Step 1: Data Collection
- Step 2: Statistical Model
- Step 3: GIS Model
- Step 4: Diagnosis
- Step 5: Countermeasure Selection
- Step 6: Economic Appraisal/Project Prioritization
- Step 7: Effectiveness Evaluation

Utah Safety Mitigation Framework

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Step 1: Data Collection

- Purpose:
  - Collect data for both roadway segments and crashes

Step 1: Data Collection

- Roadway segments developed based on the following attributes:
  - Speed limit
  - Number of through lanes
  - Average annual daily traffic
  - Functional classification
  - Urban code

Resulted in 4,151 segments statewide

Step 1: Data Collection

- Crash data provided by the Utah Department of Transportation (UDOT) with three levels of data:
  - Crash
  - Vehicle
  - People

Utah Safety Mitigation Framework

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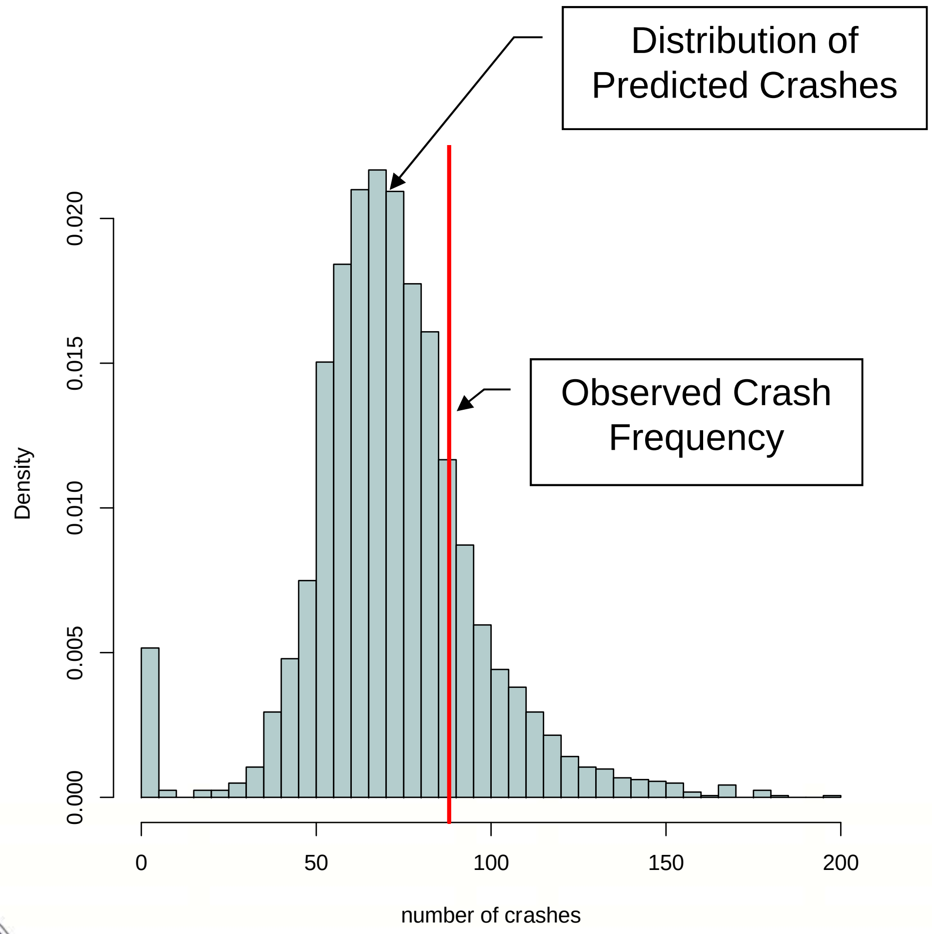
Step 2: Statistical Model

- Purpose:
  - Utilize existing information (prior information) and all available data to develop a posterior predictive distribution (future prediction of crashes) to identify ‘hot spots’ or ‘black spots’ across the state

Step 2: Statistical Model

- Process:
  - Hierarchical Bayesian model developed to obtain posterior predictive distributions for each parameter in the model for every segment
  - Compare actual number of crashes with posterior predictive distribution to determine where the actual falls with respect to the predicted
  - Assign a percentile to the actual number of crashes (between 0 and 1) based on where it falls in the distribution

Step 2: Statistical Model



Posterior predictive distributions tell the analyst how probable the observed number of crashes are given the model

Percentile ~0.72

Utah Safety Mitigation Framework

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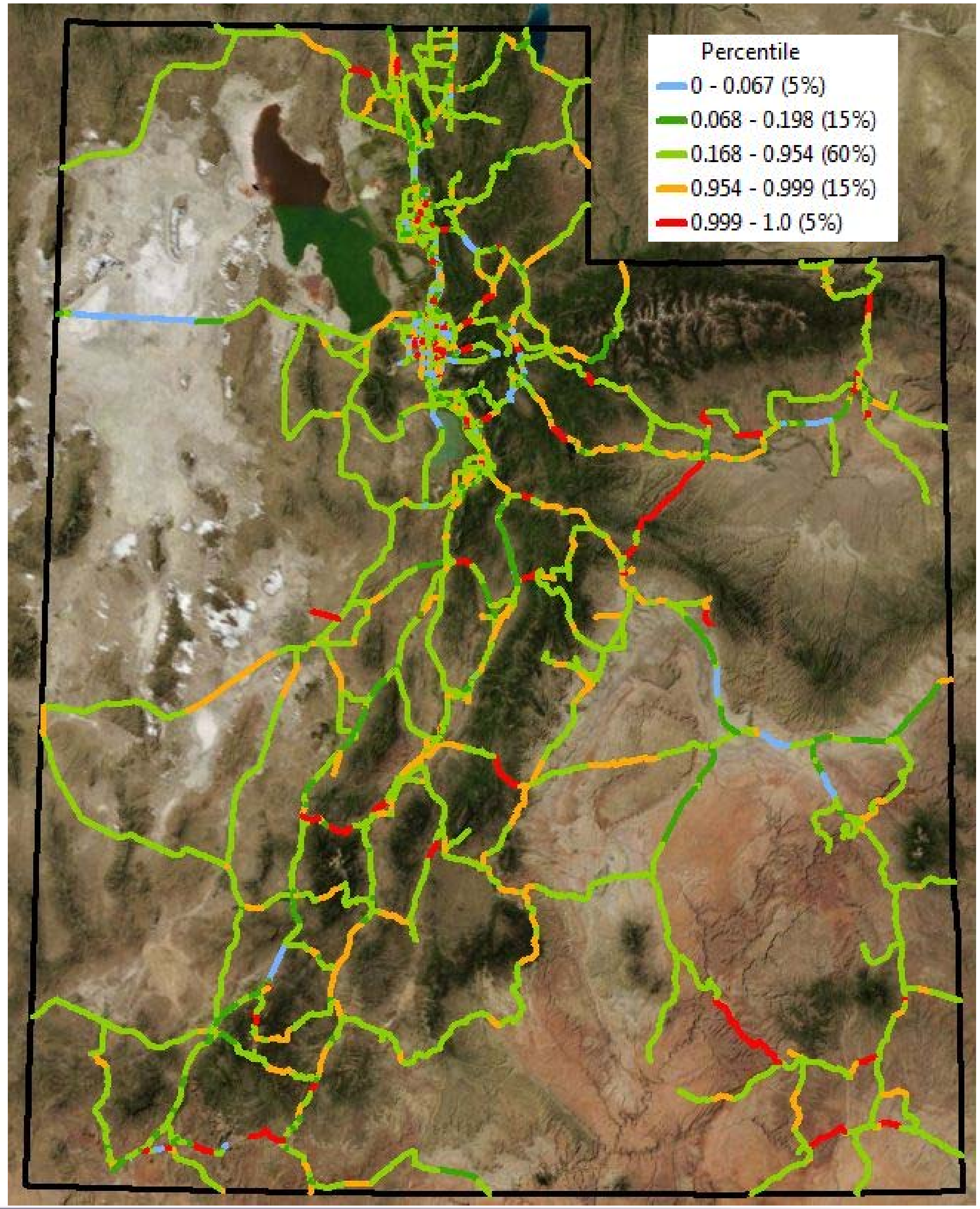
Step 3: GIS Model

- Purpose:
  - 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

Step 3: GIS Model

- Process:
  - Import the results of the statistical model to ArcMap/ArcGIS
  - Map the segments using the state linear referencing system
  - Display the results using a color scale that corresponds to the percentile (i.e., crash risk) outlined in Step 2

Step 3:
GIS Model



Utah Safety Mitigation Framework

- Step 1: Data Collection
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- Step 7: Effectiveness Evaluation

Step 4: Diagnosis

- Purpose:
  - To better identify 'hot spots' along segments to identify appropriate countermeasures
- Process:
  - Utilize advanced GIS tools such as spot analysis, strip analysis, and sliding scale analysis to evaluate each segment identified as a 'hot spot' in order to pinpoint crash clusters

Utah Safety Mitigation Framework

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Step 5: Countermeasure Selection

- Purpose:
  - Identify possible countermeasures that will reduce crash frequency or crash severity
- Process:
  - Identify factors contributing to crashes
  - Identify potential countermeasures
  - Evaluate treatment based on economic analysis

Example Countermeasures

- Rear-end collisions:
  - Right/left turn bays
  - Realign road for better sight distance
  - Advanced warning lights

Utah Safety Mitigation Framework

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Step 6: Economic Appraisal/ Project Prioritization

- Purpose:
  - Determine if a safety improvement project is economically valid by comparing benefits and costs of the project
  - Organize potential projects into an ordered list that will maximize the benefit from highway safety investment

Step 6: Economic Appraisal/ Project Prioritization

- Process:
  - Assess benefits of project
  - Estimate project cost
  - Apply economic evaluation methods
  - Rank sites by economic or benefit-cost criteria
  - Optimize projects to fit within budget constraints

Utah Safety Mitigation Framework

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Step 7: Effectiveness Evaluation

- Purpose:
  - Assess the change in safety brought about by the implementation of countermeasures
- Process:
  - Track progress and performance using before/after studies to determine countermeasure effectiveness
  - Develop CMFs for the countermeasures

Conclusions

- Purpose:
  - 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 evaluate and identify mitigating factors to help improve safety statewide

Conclusions

- The general methodology is adapted from the HSM and includes seven steps:
  - Step 1: Data Collection
  - Step 2: Statistical Model
  - Step 3: GIS Model
  - Step 4: Diagnosis
  - Step 5: Countermeasure Selection
  - Step 6: Economic Appraisal/Project Prioritization
  - Step 7: Effectiveness Evaluation

Conclusions

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

Questions

- For more information, contact:

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Full reports on UDOT website under "Published Research Reports"

Step 2: Statistical Model

Poisson Mixture Model – Probability density function:

$$P(Y_i) = \begin{cases} p_i + (1-p_i)e^{-\lambda_i} & \text{if } Y_i = 0 \\ (1-p_i)\dfrac{e^{-\lambda_i}\lambda_i^{Y_i}}{Y_i!} & \text{otherwise} \end{cases}$$

where

$$\log(\lambda_i) = \beta_0 + VMT_i\beta_1 + SpeedLim_i\beta_2$$

$$\log\left(\frac{p_i}{1-p_i}\right) = \gamma_0 + VMT_i\gamma_1 + SpeedLim_i\gamma_2$$

and $P(Y_i)$ is the probability that Y_i crashes occur on segment i and p_i is the probability that segment i has no crashes. Thus $(1-p_i)$ is the probability that segment i follows the $Poisson(\lambda_i)$ distribution.

So we can say that crashes on segment i follow a $Poisson(\lambda_i)$ distribution with probability $(1-p_i)$ and are 0 with probability p_i. This defines a mixture distribution.