Innovations in Traffic Safety and Mobility

Risk Based Traffic Safety Research

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• CAIT Focus: USDOT Strategic Areas >>
Questions

• Why do traffic accidents happen?
  - Driver behavior?
  - Road?
  - Vehicle?
  - Traffic flow, weather, etc.?
  - Traffic signals and law enforcement?
  - All of the above?

• How to mitigate traffic safety risks?
  - Traditional reactive & systematic approach to safety planning and engineering
  - Proactive safety measures – systemic approach
  - Near real-time situational awareness for drivers
  - Near real time situational awareness for law enforcement
  - Smart and connected cars & smart roadways
  - Self-regulating smart cars – advanced cruise control/drive by-wire
  - Near real-time and dynamic insurance pricing
• Inception 2006

• Safety/mobility resource center funded by FHWA and NJ DOT

• Development of new technologies (e.g., Plan4Safety or P4S)

• Services to NJ DOT/ FHWA/ municipalities/counties/law enforcement

• TSRC has been a major force in effectively improving traffic safety in New Jersey.
Rutgers Plan4Safety (P4S)
<table>
<thead>
<tr>
<th>Ring 5 – Presentation</th>
<th>Ring 4 – Connection to other management systems</th>
<th>Ring 3 – Applications</th>
<th>Ring 2 - Advanced Functions</th>
<th>Ring 1 – Core &amp; Basic functions</th>
</tr>
</thead>
</table>

- **Engineers**
- **Planners**
- **Officers**
- **General Public**
- **Public Officials**

**Safety Analysis**
- Using historical crash data
  - Safety Performance Function
  - Crash Modification Factor (CMF)
  - Scenario generation & diagnosis analysis
  - Cost & benefit analytics
  - Advanced Filtering
  - Extended GIS mapping
  - Routing & Navigation
  - Crash prediction

**Safety Planning**
- Using near miss data
  - Data fusion
  - Crash prediction
  - Hot spots
  - Near Crash Analysis

**Safety Engineering**
- Using hybrid data
  - Crash forecasting
  - Driver violation check
  - Safety and Mobility Analysis
  - Post-Crash Health Economics
  - Safety Grant Eligibility
  - Crash Impact Simulation
  - Crime Hot Spots
  - Enforcement Dispatch Routing
  - Real Time Monitoring
  - Post evaluation
  - Driver licensing

**Safety Evaluation**
- Using hybrid data
  - Crash forecasting
  - Driver violation check
  - Safety and Mobility Analysis
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  - Crash Impact Simulation
  - Crime Hot Spots
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  - Real Time Monitoring
  - Post evaluation
  - Driver licensing

**Law enforcement**
- Using historical crash data
  - Trend Line
  - Hot spot analytics with different crash types
  - Cluster finder
  - High Risk Road Segments
  - Crash Rates
  - Critical Crash Rate
  - Severity Rate
  - Critical Severity Rate
  - Driver violation check

**Peds and bikes**
- Using hybrid data
  - High Risk rural Roads
  - Intersection Analysis
  - Intersection ranking
  - High Risk Urban Roads

**Commercial vehicles**
- Using hybrid data
  - High Risk rural Roads
  - Intersection Analysis
  - Intersection ranking
  - High Risk Urban Roads

**Safe Navigation**
- Using hybrid data
  - High Risk rural Roads
  - Intersection Analysis
  - Intersection ranking
  - High Risk Urban Roads

**Situational Awareness**
- Using hybrid data
  - High Risk rural Roads
  - Intersection Analysis
  - Intersection ranking
  - High Risk Urban Roads

**Safety Training**
- Using hybrid data
  - High Risk rural Roads
  - Intersection Analysis
  - Intersection ranking
  - High Risk Urban Roads
Plan4Safety has won many awards, including the *USDOT Best Practice Award for the 2009 National Roadway Safety Awards*,

Plan4Safety has been recognized internationally in the Annual Showcase of 2013 in the *Intertraffic World* Magazine, published in Britain,

Among the top three safety systems recognized in the USA,

P4S is in China.
Plan4Safety (P4S) is in China

- Collaboration with Anhui Keli on traffic safety and mobility started in 2012.

- A two phase project was already completed (11/2013).

- A joint program between Anhui Keli and Rutgers on ITS will start in May 2014.

- Anhui Keli is designated as one of the main ITS companies in China by the Chinese government.
Current Technology

Historical Crash data

Static Roadway Characteristics

Historical Weather data

Traditional Safety Prediction Models
- Non-individualized
- Passive

\[ \#\text{(Crashes)} = f(\text{Some Driving Features, Static Roadway Features, ...}) \]

Network Screening

Crashes are Rare Events!
Safety Predictive Analytics – Historical data

Historical Database
- Crash Records
- Traffic Volume Data

Roadway (Engineering) Database:
- length of segment, lane width, shoulder width, shoulder type, roadside hazard rating, presence or absence of horizontal curve, curve characteristics, Lighting, Speed Limit and ....

How to find a good model?

- Based on AADT and Roadway Length
- Models were developed by data from specific states

Predicative Model

\[ Y_i(t) = \text{Average Crash Frequency} \]
For site \( i \) at time \( t \)

\[ X_1(t) X_2(t) \ldots X_k(t) \]
\[ Z_1 Z_2 \ldots Z_n \]

SPF Crash Modification Factor Calibration Factor Empirical Bayesian Method Average Crash Frequency

Inputs

\[ N_{predicted} = SPF \times (CMF1 \times CMF2 \times \ldots) \times C \]
\[ N_{expected} = w \times N_{predicted} + (1-w) \times N_{observed} \]
Safety Predictive Analytics – Historical data

Poisson Model (popular model)

\[ N_i(t): \text{# of crashes in site } i \text{ and year } t \]

\[ f(N_i(t), \lambda_i) = e^{-\lambda_i} \frac{(\lambda_i t)^{N_i(t)}}{N_i(t)!} \]

\[ E(N_i(t)) = \exp \left( \sum_{j=0}^{p} \beta_j x_j \right) \]

Average crash at site \( i \) and year \( t \)

Roadway characteristics and traffic information

Negative binomial model

Assume that the Poisson parameter is random variable (with gamma distribution)

\[ f(N_i(t) \mid x_i, \lambda_i, \nu, \delta) = \int_{0}^{\infty} e^{-\lambda_i} \frac{(\lambda_i)^{N_i}}{N_i!} G(\lambda_i \mid \nu, \delta).d\lambda_i \]

\[ f(N_i \mid x_i, \nu, \delta) = \frac{\Gamma(\nu + N_i)}{\Gamma(\nu)\Gamma(N_i + 1)} \left( \frac{\delta}{1 + \delta} \right)^{\nu} \left( \frac{1}{1 + \delta} \right)^{N_i} \]

\[ f(N_i \mid x_i, \alpha, \delta) = \frac{\Gamma(N_i + 1/\alpha)}{\Gamma(1/\alpha)\Gamma(N_i + 1)} \left( \frac{1}{1 + \alpha \mu_i} \right)^{1/\alpha} \left( 1 - \frac{1}{1 + \alpha \mu_i} \right)^{N_i} \]

\[ E(N_i) = \mu_i = \exp \left( \sum_{j=0}^{p} \beta_j x_j \right) \]
Input features and response variables used for building the proposed crash prediction model:

### Input Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Data Type</th>
<th>Base Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_1$ Road Segment ID</td>
<td>Number</td>
<td>-</td>
</tr>
<tr>
<td>$x_2$ SRI</td>
<td>Text</td>
<td>-</td>
</tr>
<tr>
<td>$x_3$ Location Type</td>
<td>Categorical</td>
<td>-</td>
</tr>
<tr>
<td>$x_4$ Facility type</td>
<td>Categorical</td>
<td>-</td>
</tr>
<tr>
<td>$x_5$ Road Segment Length</td>
<td>Real</td>
<td>-</td>
</tr>
<tr>
<td>$x_6$ Start-Point</td>
<td>Real</td>
<td>-</td>
</tr>
<tr>
<td>$x_7$ End-Point</td>
<td>Real</td>
<td>-</td>
</tr>
<tr>
<td>$x_8$ Number of Lane</td>
<td>Integer</td>
<td>-</td>
</tr>
<tr>
<td>$x_9$ Road Total Width</td>
<td>Real</td>
<td>-</td>
</tr>
<tr>
<td>$x_{10}$ Speed Limit</td>
<td>Integer</td>
<td>-</td>
</tr>
<tr>
<td>$x_{11}$ AADT</td>
<td>Real</td>
<td>-</td>
</tr>
<tr>
<td>$x_{12}$ Lane Width</td>
<td>Real</td>
<td>3.75m</td>
</tr>
<tr>
<td>$x_{13}$ Shoulder Width</td>
<td>Real</td>
<td>2.5m</td>
</tr>
<tr>
<td>$x_{14}$ Shoulder Type</td>
<td>Categorical</td>
<td>Paved</td>
</tr>
<tr>
<td>$x_{15}$ Presence of Median</td>
<td>Binary</td>
<td>absence of a lane</td>
</tr>
<tr>
<td>$x_{16}$ Median Width</td>
<td>Real</td>
<td>4.5m urban, 9.0m Rural</td>
</tr>
<tr>
<td>$x_{17}$ Median Barrier</td>
<td>Binary</td>
<td>absence of a lane</td>
</tr>
<tr>
<td>$x_{18}$ Passing lane</td>
<td>Number</td>
<td>absence of a lane</td>
</tr>
<tr>
<td>$x_{19}$ 2-way left-turn</td>
<td>Binary</td>
<td>absence of 2-way left-turn</td>
</tr>
<tr>
<td>$x_{20}$ Lighting</td>
<td>Binary</td>
<td>absence of Lighting</td>
</tr>
<tr>
<td>$x_{21}$ Presence of on-street parking</td>
<td>Binary</td>
<td>absence of on-street parking</td>
</tr>
<tr>
<td>$x_{22}$ Type of on-street parking</td>
<td>Binary</td>
<td>absence of on-street parking</td>
</tr>
</tbody>
</table>

### Response Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Data Type</th>
<th>Base Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y$ Total Crashes</td>
<td>Integer</td>
<td>-</td>
</tr>
<tr>
<td>$Y_1$ Fatal Crashes</td>
<td>Integer</td>
<td>-</td>
</tr>
<tr>
<td>$Y_2$ Major Injuries Crashes</td>
<td>Integer</td>
<td>-</td>
</tr>
<tr>
<td>$Y_3$ Minor Injuries Crashes</td>
<td>Integer</td>
<td>-</td>
</tr>
<tr>
<td>$Y_4$ Property-Only-Damage Crashes</td>
<td>Integer</td>
<td>-</td>
</tr>
</tbody>
</table>
Evolution of Traffic Safety Prediction Models

Historical Crash data

Static Roadway Characteristics

Crowdsourcing

V2V, V2I

Traditional Safety Prediction Models
- Non-individualized
- Passive

$$\#\{\text{Crashes}\} = f(\text{Some Driving Features, Static Roadway Features,...})$$

Advanced Technologies => New Data Streams

Crashes are Rare Events!

Real-time Safety Prediction Model
- Individualized
- Active

$$\Pr\{\text{Crash, Near-Crash, Baseline}\} = f(\text{Historical Crashes, Real-time Roadway, & Drivers Features, Incidents, ...})$$

Network Screening

Weather data

NDD
These new safety technologies are very helpful but they miss the interrelationship among multiple causes of risky situations!
Multiple Data Streams

Static Data
Roadway conditions, traffic signals, etc.

Dynamic data

- Weather & roadway conditions real time
- Near miss, IOT & roadway sensors
- Traffic flow data V2V, V2I & crowdsourcing

Naturalistic Driving Data

- Weather data and roadway condition can be reported near real time by sensors, vehicles, and roadway sensors.
- Crashes are rare events and crash based safety solutions are reactive; Near real time near miss data and unsafe driving conditions can protect vulnerable users, e.g., pedestrians and bicycles.
- Warnings & real time unsafe driving conditions generated between vehicles and between vehicles and infrastructure;
Illustration of Traffic Safety Risk Factors

**Target Vehicle & Driver**

- **Internal:** Vehicle and Driver data
  - Immediate past & present $X_V, X_D$ (time series data)
- **External:** Roadway characteristics $X_R$
- **Predicted driving outcome ($Y$)**
  - At time $t+1$

**External:**
- Immediate surrounding vehicles $X_S$
- Road Incidents Spatially ahead of, but temporally behind target vehicle $X_I$

**Internal & External Variables**

- Internal variables: $X_V, X_D, X_T$
- External variables: $X_R, X_S, X_I, X_W$

**V2V**

- At sample time $t$:
  - Internal variables: $X_V, X_D, X_T$
  - External variables: $X_R, X_S, X_I, X_W$
Real-Time Risk Based Safety Model

In-vehicle data

- In-vehicle’s sensors, radars, cameras, OBD devices, GPS

- Driver surveys

- Naturalistic driving database

- Vehicle and driver data

External data

- Real-time traffic flow and incidents database

- Social Media (crowd-sourced data)

- Weather database

- Environment data

Engineering data

- SLD, ESRI, State inventory, Asset health condition

- Roadway characteristics database

- Historical crashes

- Network screening index

- Police reports

Historical crash data

Prediction model

Real-time Risk Based Safety Model

Users

- Drivers

- Network owners

- Insurance companies
Classification model’s input/output

State Vector at time t:

\[ x^n = [\text{Driver, Vehicle, Road, Weather, Time, Network-Screening Factor}] \]

Internal factors

External factors

Historical Crash Data

Network-Screening Factor

Real-Time Risk-Based Safety Model

Crash risk

Real Time Alert System

- No crash
- Near crash
- Crash
Application Illustration

Near Real-Time Risk Based Safety Model (cont.)
Overall Framework

Data Fused Risk Model

Data Layer
- Naturalistic driving data
  - Weather data
- Roadway data
- Traffic flow data
- Historical crash data

Data resources
- Naturalistic driving database
  - Driver distraction
  - Driver Behavior
  - Demographics
  - Speed
  - Acceleration
- Weather data
- SLD database
  - Type of road
  - Through lanes
  - Inside/outside shoulders
  - Median type
  - Surface description
- Traffic flow data
  - Accident ahead
  - Dangerous intersection
  - Work zone
  - Speed camera
  - Dangerous curves
- Historical crash database

Tools
- Simulation
- Regression models
- Classification models
- Multivariate Time Series model

Risk function
- Real-time Risk Based Safety Prediction Model