Rutgers
Center for Advanced Infrastructure and Transportation

Innovations in Traffic Safety and Mobility

Risk Based Traffic Safety Research
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• CAIT Focus: USDOT Strategic Areas

- State of Good Repair
- Economic Competitiveness
- Safety
- Asset Management
- Advanced/Innovative Materials & Devices
- Construction Management & Innovation
- Advanced Infrastructure Monitoring
- Environmental Sustainability
- Livable Communities
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)
Plan4Safety Functional Architecture

<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>
<tbody>
<tr>
<td>• Engineers</td>
<td>• Road pavement Management</td>
<td>• Safety Analysis</td>
<td>Using historical crash data</td>
<td>Using historical crash data</td>
</tr>
<tr>
<td>• Planners</td>
<td>• ITS management</td>
<td>• Safety Planning</td>
<td>• Safety Performance Function</td>
<td>• Trend Line</td>
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<tr>
<td>• Officers</td>
<td>• Bridge</td>
<td>• Safety Engineering</td>
<td>• Crash Modification Factor (CMF)</td>
<td>• Hot spot analytics with different crash types</td>
</tr>
<tr>
<td>• General Public</td>
<td>• Law Enforcement</td>
<td>• Safety Evaluation</td>
<td>• Scenario generation &amp; diagnosis analysis</td>
<td>• Cluster finder</td>
</tr>
<tr>
<td>• Public Officials</td>
<td>• Traffic Control Center</td>
<td>• Law enforcement</td>
<td>• Cost &amp; benefit analytics</td>
<td>• High Risk Road Segments</td>
</tr>
<tr>
<td></td>
<td>• Emergency Management</td>
<td>• Peds and bikes</td>
<td>• Advanced Filtering</td>
<td>• Crash Rates</td>
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<tr>
<td></td>
<td>• Management</td>
<td>• Commercial vehicles</td>
<td>• Extended GIS mapping</td>
<td>• Critical Crash Rate</td>
</tr>
<tr>
<td></td>
<td>• Capital Planning</td>
<td>• Safe Navigation</td>
<td>• Routing &amp; Navigation</td>
<td>• Severity Rate</td>
</tr>
<tr>
<td></td>
<td>• Public Transit</td>
<td>• Situational Awareness</td>
<td>• Crash prediction</td>
<td>• Critical Severity Rate</td>
</tr>
<tr>
<td></td>
<td>• Asset Management</td>
<td>• Safety Training</td>
<td>• Using near miss data</td>
<td>• Basic filtering</td>
</tr>
<tr>
<td></td>
<td>• Risk Management</td>
<td>• Using hybrid data</td>
<td>• Data fusion</td>
<td>• Basic GIS mapping</td>
</tr>
<tr>
<td></td>
<td>• Public Information Portal</td>
<td>• Crash forecasting</td>
<td>• Crash prediction</td>
<td>• Crash summary</td>
</tr>
<tr>
<td></td>
<td>• Insurance Management</td>
<td>• Driver violation check</td>
<td>• Hot spots</td>
<td>• Road Histogram</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Near Crash Analysis</td>
<td>• Basic reporting</td>
</tr>
</tbody>
</table>

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

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

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

Crashes are Rare Events!
Safety Predictive Analytics – Historical data

**How to find a good model?**

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

**Inputs**

\[ N_{\text{predicted}} = \text{SPF} \times (\text{CMF1} \times \text{CMF2} \times \ldots) \times C \]

\[ N_{\text{expected}} = w \times N_{\text{predicted}} + (1-w) \times N_{\text{observed}} \]

**Predictive Model**

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

**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 ....

**Historical Database**
- Crash Records
- Traffic Volume Data

**Adjust the calculated SPF predicted value for base conditions to actual or proposed conditions**

**Adjust SPF to reflect local conditions:**
- Climate, Driver populations, Animal populations, Crash Reporting System.

**Improve crash estimations by combining predicted data with historical 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 ....

**Empirical Bayesian Method**

**Average Crash Frequency**
Safety Predictive Analytics – Historical data

Poisson Model (popular model)

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

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

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

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)

\[ f(N_i(t) | x_i, \lambda, \nu, \delta) = \int_0^\infty e^{-\lambda_i} \frac{\lambda_i^{N_i}}{N_i!} G(\lambda_i | \nu, \delta).d\lambda_i \]

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

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

\[ E(N_i) = \mu_i = \exp(\sum_{j=0}^{p} \beta_j x_j) \]
Safety Predictive Analytics – Historical data

Input features and response variables used for building the proposed crash prediction model:

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

Response Variables

- $Y$ Total Crashes: Integer
- $Y_1$ Fatal Crashes: Integer
- $Y_2$ Major Injuries Crashes: Integer
- $Y_3$ Minor Injuries Crashes: Integer
- $Y_4$ Property-Only-Damage Crashes: Integer
Evolution of Traffic Safety Prediction Models

Historical Crash data

Static Roadway Characteristics

Crash

Near-Crash

Baseline

V2V, V2I

Network Screening

Crowdsourcing

Weather data

NDD

Traditional Safety Prediction Models
- Non-individualized
- Passive

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

Advanced Technologies => New Data Streams

Real-time Safety Prediction Model
- Individualized
- Active

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

Crashes are Rare Events!
Smart and connected vehicle technology

Single crash cause at a time

Smart car Example: Blind Spot Warning

Smart phone Example: Forward Collision Warning

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

Internal:
Vehicle and Driver data
Immediate past & present
$X_V, X_D$ (time series data)

External:
Road Incidents
Spatially ahead of, but temporally behind target vehicle
$X_I$

External:
Immediate surrounding vehicles
$X_S$

Predicted driving outcome ($Y$)
At time $t+1$

External:
Roadway characteristics
$X_R$

Target Vehicle & Driver

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:
- V2V, V2I
- Social Media (crowd-sourced data)
- Real-time traffic flow and incidents database
- Weather data
- Environment data
- External data

External data:
- Engineering data
- Historical crash data

Prediction model:
- Real-time Risk Based Safety Model

Users:
- Drivers
- Network owners
- Insurance companies
Real-Time Risk Based Safety Model (cont.)

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

Application Illustration

- Time
- State
- Risk

Diagram showing a sequence of states and risk over time, with intervals marked every 30 seconds.
Overall Framework

Data Fused Risk Model

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

Data resources
- Naturalistic driving database
  - Driver distraction
  - Driver Behavior
  - Demographics
  - Speed
  - Acceleration
- 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