New Opportunities in Predictive and Pro-active Traffic Safety Evaluation and Management in the Era of Smart Cities

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Vision Zero Town + Gown Research on the Road
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Safety Facts

▪ Each year, there are about **1.35 million road traffic deaths and 50 million injured worldwide**.

▪ **Road crashes are expected to rise to the 7th leading cause of death by the year 2030.**

Police-Reported Crash Data

Use Cases

- Crash Risk Factor Analysis
- High-Risk Location Identification
- Treatment Development
- Before-after Evaluation

Limitations

- Long Data Collection Time
- Under-Reporting Issue
- A Reactive Approach

A large number of crashes need to occur before analysis can be conducted.

c2smart.engineering.nyu.edu
Surrogate Safety Measures

- Surrogate Safety Measures (SSMs):
  - Used to identify traffic conflicts or “near-misses”.
  - Extracted from vehicle trajectories.

- Traffic safety risk can thus be reflected by the identified traffic conflicts.

- A more proactive approach.

Traditionally, the collection of vehicle trajectories is relatively difficult or time consuming.
Emerging Technologies

- In the era of smart cities, the collection of vehicle trajectories becomes easier due to various emerging technologies.
New York City is one of three **Connected Vehicle (CV) pilot deployment** sites selected by USDOT to demonstrate the benefits of this new Connected Vehicle technology.

The CV technology is a new tool to help NYC reach its **Vision Zero** goals to eliminate traffic related deaths and reduce crash related injuries and damage to both the vehicles and infrastructure.

- **3000+ vehicles**
- **450+ Roadside Units**
- **14 Mobility and Safety Applications** (include one that supports people with visual disabilities)

**NYC Connected Vehicle pilot deployment Website:** [https://cvp.nyc](https://cvp.nyc)
USDOT Other Connected Vehicle Pilot Deployment

- **Wyoming Connected Vehicle Pilot**
  - Objective: improving safety and travel reliability on I-80 in Wyoming
  - Scope:
    - 400 instrumented vehicles
    - 75 roadside units

- **Tampa Connected Vehicle Pilot**
  - Objective: transform the experience of drivers, transit riders and pedestrians in downtown Tampa by preventing crashes, enhancing traffic flow, improving transit trip times and reducing emissions of greenhouse gases.
  - Scope:
    - Over 1000 privately owned vehicles
    - 10 buses
    - 8 streetcars
    - 46 roadside units
Video-Based Safety Evaluation (Work funded by AIG)

- **Goals:** Advance data-driven traffic analytics to enhance Global Resilience

- **Objectives:**
  - Propose a novel approach for examining traffic safety performance at intersections
  - Quantify traffic conflicts using developed “surrogate” safety measures
  - Develop automatic data acquisition, analysis and modeling approaches based on computer vision techniques

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Fig. 1: Original video recording
Fig. 2: Extract feature points using Kanade-Lucas-Tomasi (KLT) Feature Tracker
Fig. 3: Group feature points using Dirchlet process mixture algorithm
Fig. 4: Convert coordinates to relative distances
Video-Based Safety Evaluation

Estimated Surrogate Events based on Automatic Tracking Results

Conflicts: TTC < 4.0 seconds
Proactive Safety Evaluation & Monitoring

Traffic risk can be quantified.

Suitable for proactive safety monitoring.

- Detect potential safety-related anomalies that may cause high traffic risk.
- Provide intervention.
Characteristics of Surrogate Events

Surrogate Events

- **Frequent**
  - Large amount of conflict data can be collected in a relatively short period of time (e.g., hours or days)

- **Detailed temporal and spatial information**
  - e.g., accurate at the second and the lane level


Crashes

- **Rare events**
  - Often take months or years to accumulate.

- **Rough location and time information**
  - e.g., at the intersection level

How to represent safety risk? What method should we use to capture these characteristics?

Often aggregated yearly or monthly for statistical modeling.
Functional Data Analysis

- A typical example
  - X axis: 12 months from January to December
  - Y axis: mean temperature
  - Each curve: one weather station in Canada
- Formally, FDA is
  - A branch of statistics that analyzes data providing information about curves, surfaces or anything else varying over a continuum.
  - The physical continuum over which these functions are defined is often time.

Figure 1.6 from Ramsay and Silverman (2005).
Functional Data Analysis for Proactive Safety Monitoring

- Analogously, for signalized intersections with pre-timed signal mode.
  - Model time series of traffic risk to detect green intervals with safety-related anomalies.

<table>
<thead>
<tr>
<th>Safety Risk</th>
<th>Start of the green interval</th>
<th>End of the green interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Interval 1</td>
<td>Safety-related anomalies occur</td>
<td>Safety-related anomalies occur</td>
</tr>
<tr>
<td>Green Interval 2</td>
<td></td>
<td></td>
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<tr>
<td>Green Interval 3</td>
<td></td>
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<tr>
<td>Green Interval 4</td>
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</tbody>
</table>

Safety Risk:
- Number of surrogate events / number of vehicles (unit: second)

Safety-related anomalies:
- **Type 1**: vehicles commit dangerous or illegal lane changing behaviors.
- **Type 2**: vehicles slow down or stop unexpectedly or abruptly.
- **Type 3**: vehicles blocked by other vehicles in the crossing directions.
Key Steps in Functional Data Analysis

- **Two key steps of using FDA for proactive safety monitoring:**
  - **Step 1:** Data representation – Functional data smoothing
    - Convert from discrete observations to continuous functions for further mathematical analysis.
  - **Step 2:** Extract functional outlier detection measures from the estimated functional curves for outlier detection.
Data Collection

- **Location: Flatbush Avenue & Tillary Street**
  - Study movement: the northbound throughput (NBT) direction.
- **Time: Morning peak period (6 AM to 8 AM)**
Data Collection

- Extraction of vehicle trajectories
  - Anonymous vehicle trajectories were extracted from the recorded UAV videos by a company called Data From Sky.
  - Longitude & latitude, speed, acceleration, and vehicle type

<table>
<thead>
<tr>
<th>Time</th>
<th>Vehicle ID</th>
<th>Vehicle Type</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Speed</th>
<th>Acceleration (longitudinal)</th>
<th>Acceleration (lateral)</th>
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</table>
Results: Smoothing Functional Curves

- **Findings:**
  - Distinct separation between outliers and non-outliers.
  - Peaks at the beginning of the green interval.
    - Caused by early acceleration of vehicles in queue before the acceleration of the vehicles in front.
    - This pattern cannot be revealed if traffic risk is aggregated into summary statistics of any kind.
Results: Receiver Operating Characteristics (ROC) & Precision-Recall (PR) curves

Findings

- Overall, ROC curves of all the functional outlier detection measures are above the random classifier line.
- PR curves show similar patterns.

9 functional outlier detection measures are compared.
Results: Area Under the Curve (AUC)

- **Findings:**
  - Best outlier detection measures is consistent for both ROC and PR AUC values.
    - Consistent between ROC-AUC and PR-AUC
  - Good separation between normal and abnormal cases are achieved.

<table>
<thead>
<tr>
<th></th>
<th>FMD</th>
<th>MD</th>
<th>RP</th>
<th>RPD</th>
<th>RT</th>
<th>FSD</th>
<th>KFSD ✓</th>
<th>Bivariate Score Depth</th>
<th>Bivariate Score Density</th>
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<td>0.70</td>
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<tr>
<td><strong>AUC-PR</strong></td>
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<td>0.80 ✓</td>
<td>0.42</td>
<td>0.68</td>
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</table>
Practical Implementation

**Step 1:** Collect real time data feed

**Step 2:** Generate new risk function

**Step 3:** Calculate outlier detection measure

**Step 4:** Identify anomalies based on a preset threshold.

Reservoir of historically identified normal risk functions
Our Paper

  - DOI: https://doi.org/10.1016/j.trc.2021.103130
What About Crash Data?

- Only surrogate events are used above to quantify traffic safety risk.
- However, both crash data and surrogate events can provide information regarding traffic safety conditions.
  - Most of the studies in the literature used only one of these.
  - However, this may lead to inaccurate safety estimates, which accordingly may lead to incorrect decision making and waste of sources.
- It is important to combine both of these together in a robust way.
Integration of Crashes and Safety Risk for Safety Analysis

- Integrating both crash data and safety risk may result in more comprehensively evaluation of traffic safety.

- Methods we proposed:
  - Surrogate Events
  - Crash Data
  - Joint modeling approaches in statistics
  - Modeling more than one outcome variable simultaneously to understand the relationships among variables.
  - Multivariate Spatial Models
  - Copula Approach
  - Structural Equation Modeling
  - Dependency Structure Analysis
  - New Safety Measure by Integration
  - Crash Count Prediction
  - High-Risk Location Identification
Our Research


The Future of Proactive Safety Management

- Other potential approaches for integrating surrogate events and crashes
- Other potential use cases of functional approach in transportation safety
  - Facilitate proactive safety management for signalized intersections
  - Calibration of microsimulation models for safety evaluation
  - Signal timing optimization accounting for safety
  - Ramp-metering control strategy development accounting for safety
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