A Novel Approach to Evaluate Pedestrian Safety at Unsignalized Crossings using Trajectory Data

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Outline

1. Motivation & Literature Review

2. Framework Description

3. Model Illustration – Case Study

4. Conclusion & Future Work
1. Motivation & Literature Review
Unsignalized Locations – Not “controlled by traffic signal” (UIIG 2016)

- Uncontrolled, no device assigning right-of-way
- Yielding sign controlled
- Stop controlled
- Volume is relatively low, but crash frequency keeps high
- US – over 70 % fatal crashes, 2010-2012
Past Methodologies

undergoing literature review project

Road Safety

Estimated using Factors Associated with Crashes
- Road Traffic
- Conflicts
- Behavior and Compliance
- Perception of Safety

Evaluated using Historical Crash Data

Crash Risk
Past Methodologies

- Behavior Measures – Yielding behavior, crossing decision measures
- Traffic Conflict Techniques (TCT) – PET, TTC, ET etc.
Past Methodologies

Hyden’s Pyramid

Behavior & Conflicts - Refined

- Accidents
- Near accidents
- Slight conflicts
- Potential conflicts
- Undisturbed passages

- Fatal
- Severe injury
- Slight injury
- Damage only
Past Methodologies

Limitations of Currently used Conflict & Behavior Measures

Conflict – not quite suitable

• TTC – constant velocity
• PET – waiting is ignored
• Severity not included (speed)
Past Methodologies

Limitations of Currently used Conflict & Behavior Measures

Behavior – less explored, and much unexplained

- Yielding – situation of being too close
- Crossing – narrowly studied, off-road experiments
- Quantify event severity using behaviors is limited
Motivation

- 99% of crashes were due to human factors – behavior/reaction

- Find a potential solution using behavior measures that could address all the previous mentioned issues
2. Methodological Framework
The Framework for Pedestrian Safety

Fu et al., TRB 2017, submitted to AAP (Minor Revision Required)
Main Assumptions

Model Explanation

Safety Measures

• Behavior Measures
  ✓ Yielding compliance
  ✓ Crossing decision

• Collision Risk Measures
  ✓ Time to Crossing
  ✓ Deceleration Rate Required to Stop
Main Assumptions

- **Drivers**: perfect knowledge of being able to stop in front of the crosswalk.
- **Maximum deceleration rate**: decided by the pavement friction rate.

Drivers showing intention or start to cross the street.
Some Basic Definitions

- Pedestrian Occurrence
- Pedestrian Crossing Decisions
- Pedestrian Groups

Refer to Fu et al., AAP for details.
Main Assumptions

Model Explanation

Safety Measures

- Behavior Measures
  ✓ Yielding compliance
  ✓ Crossing decision

- Collision Risk Measures
  ✓ Time to Crossing
  ✓ Deceleration Rate Required to Stop
Model Explanation

Based on these assumptions, whether the driver is able to stop can be decided by the distance (D) and approaching speed (v) of the vehicle.

Minimum stopping distance ($D_{\text{min}}$) - the minimum required distance for the vehicle to make a stop (stop distance)

$$D_{\text{min}} = vt_r + \frac{v^2}{2g(\mu_{\text{max}}-\theta)}$$

If $D > D_{\text{min}}$, they are required to stop.

As $t_r \in [t_{r_{\text{min}}}, t_{r_{\text{max}}}]$,

$$D_{\text{min}} \in [D_0, D_1] = [vt_{r_{\text{min}}} + \frac{v^2}{2g(\mu_{\text{max}}-\theta)}, vt_{r_{\text{max}}} + \frac{v^2}{2g(\mu_{\text{max}}-\theta)}]$$

where $v$ is the approaching speed of the vehicle, $t_r$ is the perception-reaction time, $\mu_{\text{max}}$ is the maximum friction rate the road can provide for braking, $g$ is the acceleration of gravity, $\theta$ is the slope angle of the road. When vehicle distance is greater than the minimum stopping distance, they are required to stop and yield.
Model Explanation

- **Phase I vehicles cannot make full stop**
- **Phase II Yielding depends on reaction time**
- **Phase III Vehicles can yield**

Line A - Distance and velocity of the approaching vehicle:
- ♦ When pedestrian appears
- ▲ When pedestrian crossing decision is made
- ★ Braking maneuver after reaction
Main Assumptions

Model Explanation

Safety Measures

- **Behavior Measures**
  - Yielding compliance
  - Crossing decision

- **Collision Risk Measures**
  - Time to Crossing
  - Deceleration Rate Required to Stop
Behavior Measures

![Graph showing yielding behavior with distance and velocity as axes. The graph includes zones labeled as Non-yielding Violation, Confusing Non-yielding Maneuver, and Non-infract Non-yielding.](image-url)
Behavior Measures

Yielding Ratios

**Yielding Rate** - Portion of vehicles that yield among all the interactions of interest

**Yielding Compliance** - Portion of vehicles that yield right-of-way among the drivers who are physically able to yield when they pay attention
Behavior Measures

Uncertainty Zone
Behavior Measures

Crossing decision – Ratios of Crossing Decisions

![Graph showing the relationship between distance (m) and velocity (m/s) for different crossing decisions: Safe, Risky, and Dangerous. Legend indicates distance thresholds for each decision level.](image)
Collision Risk Measures – Event Analysis

- Interaction intensity measures: TC & DRSY
  - **Time to Crossing (TC)** – the time required for the vehicle to reach the pedestrian crossing path if continuing at constant speed, presented as
    \[ TC = \frac{D}{v} \]
  - **Deceleration Rate Required to Stop (DRS)** – average deceleration rate required for the vehicle to stop and give right-of-way to pedestrians, assuming the driver pays attention to the pedestrian
    \[ DRS = \frac{v^2}{2(D-vt_{r\text{\_min}})} \text{, if } D > vt_{r\text{\_min}} \]
Model Description

Model Illustration Through A Case Study
3. Case Study
## Sites

### Descriptions of the Video Recorded at Each Site

<table>
<thead>
<tr>
<th>Type of Crosswalk</th>
<th>Site name</th>
<th>Date</th>
<th>Time</th>
<th>Duration (hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Painted</td>
<td>Laurier_Berri</td>
<td>March 17(^{th}) 2016</td>
<td>14:00-18:40</td>
<td>4.7</td>
</tr>
<tr>
<td>Unprotected</td>
<td>Laurier_Drolet</td>
<td>June 17(^{th}) 2016</td>
<td>10:00-14:30</td>
<td>4.5</td>
</tr>
<tr>
<td>Stop signs controlled</td>
<td>13e_Belair</td>
<td>June 21(^{st}) 2016</td>
<td>09:00-13:30</td>
<td>4.5</td>
</tr>
</tbody>
</table>

### Site Name and Duration

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Data Collection

GoPro’s Hero Edition cameras are used in HD resolution
Data Processing – check the paper for details

- Semi-automated
  - using automatically extracted trajectories
  - manually identified events - pedestrian occurrences & crossing decisions
Data Processing – check the paper for details

Under the help the tracker in the open source Traffic Intelligence project
Sample Outputs

Vehicle trajectory through multiple cameras
Results – Vehicle Yielding

DV plot for yielding behavior
## Results – Vehicle Yielding

### Behavior Measures

<table>
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<tr>
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<th>Yielding rate (YR)</th>
<th>Yielding compliance (YC)</th>
</tr>
</thead>
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<tr>
<td>Painted</td>
<td>47.4 %</td>
<td>64.3 %</td>
</tr>
<tr>
<td>Unprotected</td>
<td>8.7 % (worst)</td>
<td>10.8 % (worst)</td>
</tr>
<tr>
<td>Stop Sign Controlled</td>
<td>77.8 % (best)</td>
<td>77.8 % (best)</td>
</tr>
</tbody>
</table>
Results – Vehicle Yielding

Collision Risk Measures

TC (s) vs. Painted, Unprotected, Stop Sign

DRS (m/s²) vs. Painted, Unprotected, Stop Sign
Results – Pedestrian Crossing Decisions

DV plot for yielding behavior
- **Results – Pedestrian Crossing Decisions**

Collision Risk Measures
Discussion

Results generally meet the framework assumptions. For instance, no single yielding maneuver is observed for interactions in situation 1) / Phase I.

Significant differences with huge variance between the yielding rate and the compliance were observed for the different crosswalk types.

Comparison results show that crosswalk with stop sign performs best for pedestrian safety, while the unprotected crosswalk is the least safe.
6. Conclusions & Future Work
Conclusions

A new framework is proposed to study pedestrian-vehicle interactions in a potentially more precise and microscopic way.

It can be used for different purposes including treatment evaluation, behavior analysis, safety monitoring (violation detecting), pedestrian-vehicle interaction modeling, and improving yielding enforcement policy.

Results from the case study indicate the framework works reasonably. However, the model needs to be further validated through a sufficiently large number of observations.
Data

Model Improve

Video

Others

Model Apply

Machine Learning
Tracking through multiple cameras
Pedestrian body movement detection
Drone data
GPS data
3D LiDAR

Treatment Validation
Behavior Analysis – Distraction etc.
Geometric Designs – Parking & Plants

Interaction Simulations
Autonomous vehicle - Performance validation
Cyclist – Pedestrian Interactions

ETC.

Weather & Pavement
Possibility instead of Phases
Weather & Pavement
More data for Validation
Turning vehicles
Adjust for signalized intersections
# Representative Work

## Finished


## Almost Done

1. **Project 1**: Literature Review on Methodologies in Investigating Pedestrian Safety at Unsignalized Crossings

2. **Project 2**: Literature Review on Stop Sign Safety & Operation Efficiency: Methodologies, Topics and Limitations

## Undergoing

1. **Project 3**: Investigating Pedestrian Safety at Unsignalized Locations with Different Traffic Control Methods under Different Geometric Conditions

2. **Project 4**: Cycling Attitude and Behavior towards Pedestrians in Shared Spaces using the DV Framework
Thank you!

Questions or comments?

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