Prediction of Roadway Surface Conditions Using On-Board Vehicle Sensors

Andrew (Andy) Alden, P.E.
Group Lead – VA Green Highway Initiative
Director – Smart Road Facilities
August 8, 2012
Presentation Outline

• Introduction (why)
• Vehicle-based safety systems
• Connected Vehicle integration
• Observations on instrumented vehicles
• Friction prediction concept
• Experimental verification
• Challenges, potential pitfalls
• Potential benefits
Introduction

- 24% of all vehicle crashes in the U.S. occur in adverse weather conditions
  - 7,400 deaths and 675,000 injuries on average per year (years 1995 – 2005)
  - Financial cost of $55 billion (year 2000)
- Slick pavement:
  - Primary cause of 35% and
  - Contributing cause of 63% of adverse weather crashes
- About 25% of adverse weather crashes occur on pavement impacted by snow or ice
- Road maintaining agencies spend more than $2.3 billion annually on snow and ice control operations
Vehicle On-Board Safety Systems

• Anti-lock braking systems (ABS)
  – Modulation of brake torque applied at each wheel to minimize slippage

• Electronic Stability Control (ESC) systems
  – Control of applied brake torque and actual throttle to stabilize vehicle, primarily to prevent rollover

• Traction Control Systems (TCS)
  – Modulation of brake torque at individual wheels to transfer applied engine torque to non-slipping wheels
ABS, ESC, TCS Operation

• Depend upon relatively large but short duration tire slip events (macro-slip)
• Theses systems require relatively accurate and timely wheel rotation measurement
• Wheel speed sensor
• High speed CAN network
• Opportunities for Connected Vehicle apps
Data Utilization Via Connected Vehicle, e.g.

Adaptive/optimized winter maintenance operations
Vehicle Testing on the Virginia Smart Road
Smart Road Grade – Aerial View
Tire Contact Dynamics

- Observations on instrumented vehicles
- Micro-slip
- Macro-slip (used by on-board systems)
• Rear wheel drive vehicle
• Constant speed
• Negligible road slope
Proposed Integration in CV

• Use vehicle on-board sensors data from CAN bus to determine **relative** significant changes in road friction
• Report significant changes in road friction via *Connected Vehicle* network
• Issue safety advisories to approaching vehicles
• Optimize winter maintenance operations
Experimental Methodology

• Operate instrumented vehicles on the Smart Road in various road surface and environmental conditions
• Monitor
  – Rotational rates of driven versus un-driven wheels
  – Distance traveled, weather variables, safety systems
• Determine rotational differential over time
• Predict relative friction values based on differential
• Compare to absolute friction measurements (e.g., GripTester)
  – At time of testing
  – Historical road friction data
Vehicle Data Acquisition

- Multiple Videos
  - Machine Vision Eyes Forward Monitor
  - Machine Vision Lane Tracker
- Accelerometer (linear acceleration, 3 axis)
- Gyroscope (angular velocity, 3 axis)
- GPS
  - Latitude, Longitude, Elevation, Time, Velocity
- Forward Radar
  - Tracking of 32 targets
- Cell Phone
  - ACN, health checks, location notification
  - Health checks, remote upgrades
- Illuminance sensor
- Passive alcohol sensor
- Incident push button

- Audio (only on incident push button)
- Turn signals
- Vehicle network data
  - Accelerator
  - Brake pedal activation
  - ABS
  - Gear position
  - Steering wheel angle
  - Speed
  - Seat Belt Information
  - Airbag deployment
  - Etc.
Virginia Smart Road

- 2.2 Miles controlled-access test track built to interstate standards
  - 2 paved lanes plus graded lanes
  - 3 bridges
- Pavement
  - 14 pavement sections (including open grade friction course)
  - In-pavement sensors (moisture, temp, strain, vibration, weigh-in-motion)
  - AASHTO-designated surface friction testing facility
- Control Room
  - Access control and oversight 24/7
  - Lighting and weather system control
  - Safety assurance and surveillance
- Weather
  - 75 weather-making towers (crowned and uncrowned pavement)
  - Snow up to 4”/hr.
  - Rain
  - Fog-like mist
  - Weather stations (2) plus NOAA nearby
- Lighting
  - Multiple luminaire heads including LED
  - Variable pole spacing to replicate 95% of national systems
  - Wireless mesh network control
- Communications
  - High bandwidth Fiber network
  - DSRC RSEs
  - Wi-Fi access points
  - Differential GPS base station
Artificial Precipitation on the Smart Road
Experimental Data

- GPS time and position — Real-time differential correction will be used if it is found to have sufficient accuracy for concept validation. Post-collection processing of collected raw GPS satellite data may be performed if additional positional accuracy/precision is desired.
- Wheel rotation sensor pulse counts at all wheels from the CAN bus.
- Transmission output shaft sensor (vehicle speed).
- Status of ABS, ESC, and TSC from the CAN bus. Activation of these systems during tests would likely affect the outcome and need to be recognized as a confounding influence.
- Brake activation and applied torque at all wheels.
- Throttle, both applied and actual. On “drive-by-wire” vehicles input throttle and actual throttle may not match.
- Linear acceleration in the longitudinal and vertical axes for assessment of slope and/or vehicle acceleration. Preliminary tests should reveal whether additional gyroscopic data is required in the form of use of a full inertial measurement unit (IMU).
- Variables indicative of atmospheric conditions such as temperature, atmospheric pressure, windshield wiper and headlight activation, etc.
Connected Vehicle Demonstration

• Smart Road *Connected Vehicle* test-bed
• Continuous coverage by road-side equipment (RSE) for CV vehicle data
• Roadside weather stations
• Pavement temp sensors
• Transfer via optical fiber Ethernet backhaul to Control Center – data storage/management
## Test Scenarios

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<th>Condition</th>
<th>Air Temperature</th>
<th>Pavement Temperature</th>
<th>Pavement Surface</th>
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<tbody>
<tr>
<td>A</td>
<td>35° F +</td>
<td>35° F +</td>
<td>Dry</td>
</tr>
<tr>
<td>B</td>
<td>35° F +</td>
<td>35° F +</td>
<td>Lightly wet</td>
</tr>
<tr>
<td>C</td>
<td>35° F +</td>
<td>35° F +</td>
<td>Very wet</td>
</tr>
<tr>
<td>D</td>
<td>28° F -</td>
<td>28° F -</td>
<td>Snow</td>
</tr>
<tr>
<td>E</td>
<td>35° F +</td>
<td>28° F -</td>
<td>Snow</td>
</tr>
<tr>
<td>F</td>
<td>28° F -</td>
<td>28° F -</td>
<td>Ice</td>
</tr>
<tr>
<td>G</td>
<td>35° F +</td>
<td>28° F -</td>
<td>Ice</td>
</tr>
</tbody>
</table>
Potential Challenges

• Wheel rotation data resolution
• Data acquisition from CAN bus
• Effects of
  – Road slope
  – Acceleration/deceleration
• Correlation with absolute measures of road friction
• Value of “relative” friction prediction
Potential Benefits

• Lives saved, fewer injuries
• Decreased property damage
• Better application of limited winter maintenance resources
• Increased mobility
• Decreased adverse environmental impact
Questions? Comments?

Contact Info
Andrew (Andy) Alden
Email: aalden@vt.edu
www.vtti.vt.edu
540-231-1526