Rollover Fatality Rates

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Fatality Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Vehicles</td>
<td>47</td>
</tr>
<tr>
<td>Utility Vehicle</td>
<td>98</td>
</tr>
<tr>
<td>Small Pickup</td>
<td>93</td>
</tr>
<tr>
<td>Standard Pickup</td>
<td>59</td>
</tr>
<tr>
<td>Small Car</td>
<td>47</td>
</tr>
<tr>
<td>Minivan</td>
<td>40</td>
</tr>
<tr>
<td>Standard Van</td>
<td>34</td>
</tr>
<tr>
<td>Medium Car</td>
<td>28</td>
</tr>
<tr>
<td>Large Car</td>
<td>19</td>
</tr>
</tbody>
</table>

Source: 1991-94 Average/Annual deaths per million registered vehicles provided by United States Department of Transportation

Automotive Research Center
Warning and Control of Vehicle Rollover Prevention
Traffic Safety Fact 1996

The chart illustrates the percent rollover occurrence for different vehicle types based on crash severity. The categories include:

- Passenger Car
- Light Truck: Utility
- Light Truck: Van
- Large Truck

Crash Severity is categorized into:

- Fatal
- Injury
- Property Damage Only

The chart shows a significantly higher percentage of rollovers for Light Trucks, particularly for Utility Light Trucks, compared to other vehicle types.
New SUV Rollover Stickers

WARNING: HIGHER ROLLOVER RISK

Avoid Abrupt Manouvers and Excessive Speed.

Always Buckle Up.

See Owner's Manual For Further Information.

News Released on March 5, 1999.
Rollover Warning Application

Sport Utility Vehicle

Pickup Light Truck

Heavy Truck

Introducing the International® 9000® Series
Literature Review (Rollover Warning)

- Acceleration or Roll Angle Threshold
  - Early warning safety monitor
    (Rakheja and Pichè 1990)
  - Lateral load transfer ratio
    (Preston-Thomas and Woodroffe 1990)
  - Rollover advisory sign on highway exit ramps
    (Freedman et al. 1992)
  - Automatic Truck Rollover Warning System
    (McGee et al. 1992)
  - Rollover stability advisor system
    (Winkler et al. 1998)
Literature Review (Rollover Warning)

• Energy threshold
  - Rollover Prevention Energy Reserve (RPER) (Nalecz et al. 1987)
  - RPER = the energy needed to bring the vehicle to its tip-over position – the rotational kinetic energy
  - RPER is positive for non-rollover cases, and when it becomes negative, a rollover will occur if no action is done to take energy out of the roll mode.
Disadvantages of Existing Algorithms

• The “distance” away from these threshold levels is not an intuitive measure.
• Use the information to determine the rollover threat at current time.
• A method which assess rollover threat into the future, could give us a better perspective.

New Proposal: Time-To-Rollover (TTR) metric
**Time To Rollover (TTR)**

- **TTR**: Index defined to assess rollover threat in this research.

![Diagram](attachment:image.png)
**TTR Calculations**

*Initial Conditions at the Kth Sampling Time*

- Steering Angle, Lateral Accel.
- Roll Angle of the Sprung Mass

- **Model Integrated for up to 1 Seconds**

- Yaw Model
- Roll Model
- TTR Calculation

- Lateral Acceleration
- Roll Motion

- **TTR (real-time)**

*Automotive Research Center*  *Warning and Control of Vehicle Rollover Prevention*
For rollover cases, a straight line with \textit{slope} = -1 is created starting from the rollover point backwards in time.

It gives a uniform “\textit{countdown}” toward rollover threats and thus serves well as the basis of warning/control.

The vehicle will rollover \textit{TTR} = 0.5 sec later.
Neural Network (NN) Architecture

![Diagram of Neural Network Architecture]

- TTR from Simplified Model
- Roll Angle
- Change of Roll Angle
- Inputs
- Layer 1
- Layer 2
- Desired TTR
- Output
- NN TTR
- Train NN to approach the Desired TTR
ArcSim Simulation Results

Ramp Steering

Entering a Ramp

Obstacle Avoidance

Worst-Case Steering

Automotive Research Center

Warning and Control of Vehicle Rollover Prevention
**SUV Simulation Results**

Model based TTR of Samurai  
(50 mph 0.6g right turn maneuver)

Model based TTR of Cherokee  
(50 mph 0.6g right turn maneuver)

Model based and NN TTR of Cherokee  
(50 mph 0.6g right turn maneuver)
Reducing Time Delay Helps!

- Human delays (mean for brake reaction time ~0.75 sec) creates unwanted vehicle and traffic behavior. It was found that 0.5 (1.0) second of advance warning could prevent 30-60% (60-90%) of the accidents.

**Source:** Von Glasner AVEC’94 002 9437953
Cherokee Model in TruckSim

TruckSim<sup>tm</sup>
Vehicle Dynamics Simulation

Version 4.2.1 MM (Metric Units)
for Simulink/MATLAB (C-MEX)

March 1999

MSC — Mechanical Simulation Corporation
709 West Huron, Suite 50, Ann Arbor, MI, 48103, USA
FAX (734) 686-2977, Phone (734) 686-2930
http://www.trucksim.com

Copyright 1995. The Regents of The University of Michigan.
Portions copyright Asymetrix, Inc. (ToolBook Runtime package).
All Rights Reserved.

Mechanical Simulation Corporation

Automotive Research Center
Warning and Control of Vehicle Rollover Prevention
Model Verification

50 mph pulse steer right
Lateral acceleration

![Lateral acc]  
RMS value: 0.0379 g

Vehicle roll angle

![Roll angle]  
RMS value: 0.2130 deg

25 mph right turn (0.6g)
Lateral acceleration

![Lateral acc]  
RMS value: 0.0379 g

Vehicle roll angle

![Roll angle]  
RMS value: 0.2130 deg
Literature Review (Anti-Rollover Control)

• 4-wheel Steering
  - Multiple Steered Axles for Reducing the Rollover Risks of Heavy Articulated Trucks. (Furleigh, Vanderploeg, and Oh et al. 1988)

• Active Suspension
  - An Investigation of Roll Control System Design for Articulated Heavy Vehicles. (Sampson and Cebon 1998)

• Differential Braking
  - Roll-Over Prevention (ROP®) System. (Palkovics, Semsey, and Gerum 1998)
  - Anti-Rollover Braking (ARB™). (Wielenga 1999)
Physics of Differential Braking Control (I)

- Rolling over without Differential Braking
- Inertial force
  - High C.G.
  - Reduction in the tire lateral force component
- ABS operation region
- Longitudinal tire force
- Lateral tire force
- Longitudinal Slip
- Tends to zero by roll-over

Vertical tire load
\[ a_y = \dot{v} + u \cdot r \]

- Longitudinal velocity, \( u \)
- Lateral tire force
- Lateral velocity, \( v \)
- Lateral tire force
- Yaw rate, \( r \)
- Resulting Yaw moment
- \( \delta = \text{constant} \)
The effect of differential braking has been included in TTR calculation.

Braking moment is applied on the outside front wheel while the vehicle is turning.
Simulation Maneuvers

- Step steering
  100 km/h. (62mph)

- Fishhook steering
  100 km/h. (62mph)
Step Response - Tire Force

Fz of the left front tire

Fz of the right front tire

Fz of the left rear tire

Fz of the right rear tire

No control
P-control

Automotive Research Center
Warning and Control of Vehicle Rollover Prevention
Step Response - Roll Angle

TTR

Roll Angle

Braking Moment

Roll

Yaw rate

Longitudinal speed

Lateral acceleration

Right

Start at t=0.081sec

No control

P-control

Automotive Research Center

Warning and Control of Vehicle Rollover Prevention
Fishhook Response - Tire Force

Fz of the left front tire

Fz of the right front tire

Fz of the left rear tire

Fz of the right rear tire

No control

P-control

Automotive Research Center

Warning and Control of Vehicle Rollover Prevention
Time Delay of Control Action

- The control is turned on based on the threshold of lateral acceleration or roll angle.
  - Lateral acceleration threshold = 0.4g. \( T_{\text{delay}} = 0.091 \text{ sec.} \)
  - Roll angle threshold = 3 deg. \( T_{\text{delay}} = 0.257 \text{ sec.} \)
Step Response - Tire Force. $T_d = 0.257$ sec

**Fz of the left front tire**

- No control
- P-control

**Fz of the right front tire**

- No control
- P-control

**Fz of the left rear tire**

- No control
- P-control

**Fz of the right rear tire**

- No control
- P-control

Automotive Research Center

Warning and Control of Vehicle Rollover Prevention
Conclusion

• TTR can provide *preview* rollover threat index.
• Verified by using field test data (Cherokee).
• TTR anti-rollover control can turn on the control action *up to 250msec earlier* than threshold (lateral acceleration or roll angle) based algorithms.
Future Works

- Sophisticated controller design for TTR anti-rollover control.
- Interactions between TTR warning/TTR anti-rollover control and drivers.
- Human-in-the-loop driving simulator with TTR warning/TTR anti-rollover control. (With Oakland University.)