

# Development and Validation Of Hardware in the Loop (HIL) Simulation for Studying Heavy Truck Stability Control Effectiveness

**Alrik L. Svenson**

Research Engineer

Office of Applied Vehicle Safety Research  
National Highway Traffic Safety Administration  
Washington, D.C.



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# Acknowledgements

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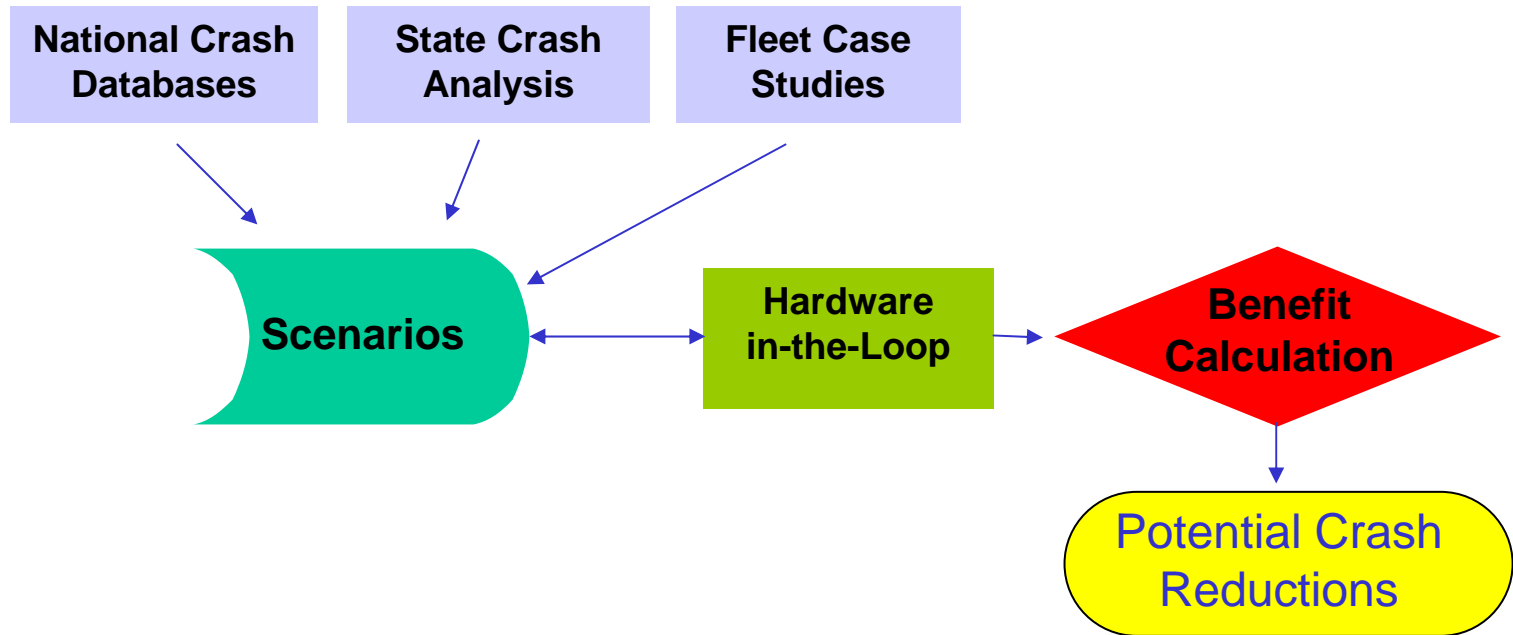
# Outline

- Introduction
- Stability Control Systems Tested
- Hardware in the Loop System (HiL)
- HiL Validation
- Crash Data Review
- Scenario Development
- Determining System Effectiveness
- Linking Effectiveness to Potential Safety Benefits
- Summary

# Introduction

- Project studied the potential safety benefits from stability control systems for heavy truck tractor semitrailers
- Determination of safety benefits is challenging
  - Stability control only recently introduced to heavy truck fleet
  - Limited crash exposure of technology in the field
  - Not possible to do a “before/after” study
- Hardware in the Loop (HiL) used to determine the effectiveness of stability control for common pre-crash scenarios determined from crash data.

# Benefits Estimation Overview



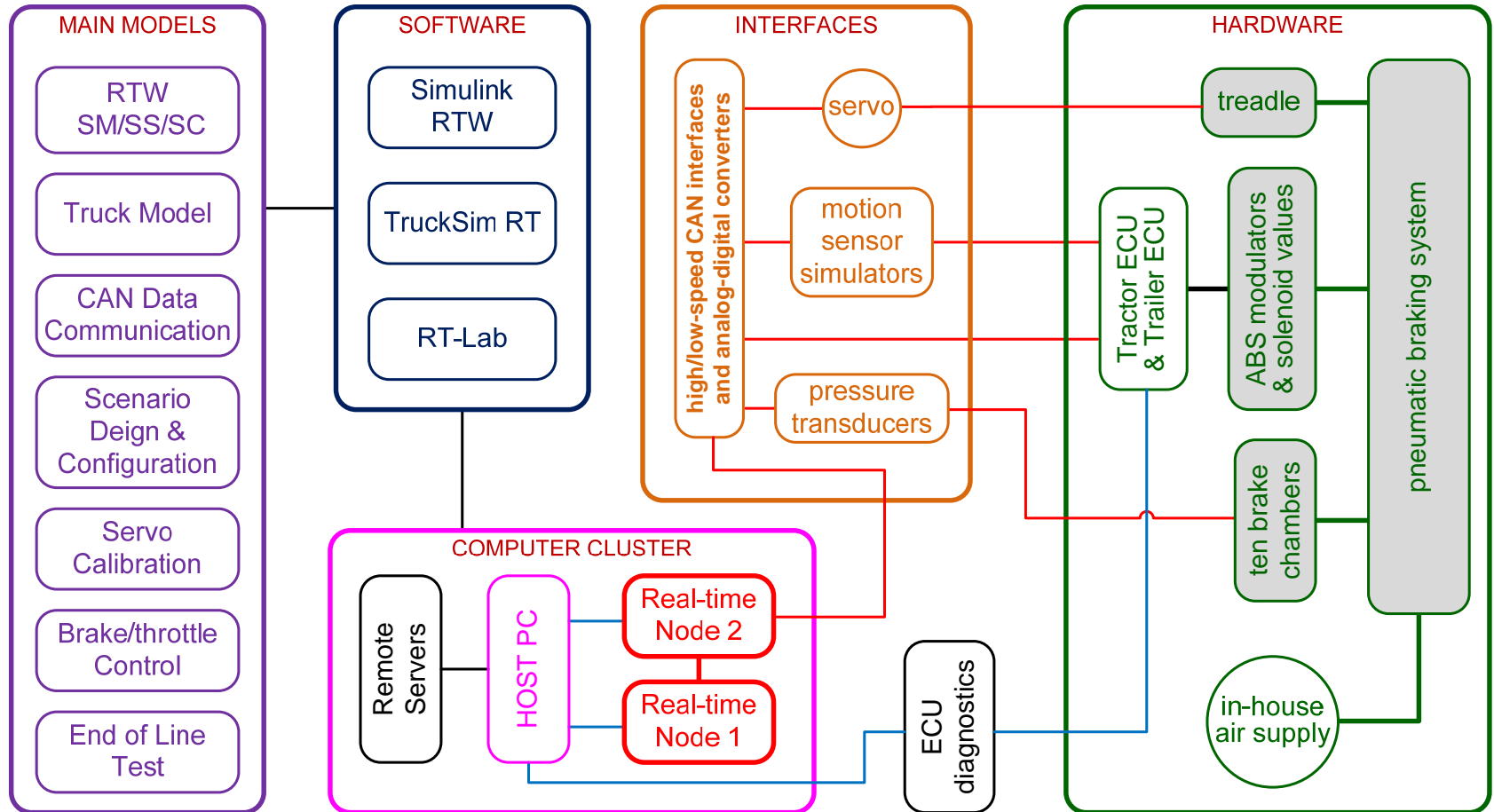
# Stability Control Systems Tested

- Roll Stability Control (RSC)
  - Senses wheel speed and lateral acceleration
  - Applies drive axle and trailer brakes when rollover is imminent
- Electronic Stability Control (ESC)
  - Includes RSC functionality
  - Also senses yaw rate and steer angle
  - Applies individual drive/steer axle brakes and trailer brakes to assist a driver in avoiding directional instabilities as a result of an understeer or oversteer mitigation process

# Hardware in the Loop System

- **HiL**- hybrid of hardware and software components
- Hardware
  - Pneumatic Brake System
  - System ECU - control algorithm for ABS (Baseline), RSC, and ESC
- Software
  - Truck Dynamics - generates truck motion, suspension, tires, powertrain, etc.
  - Driver Model - throttle, manual braking, and steering
  - Environment - road geometry and surface properties

# System Setup





# Brake System Hardware

- Transient responses of valves
- Brake actuator
- Air pressure dynamics
- Avoids modeling complex mechanical systems
- Actual control unit for ABS, ESC, and RSC (Meritor WABCO systems)



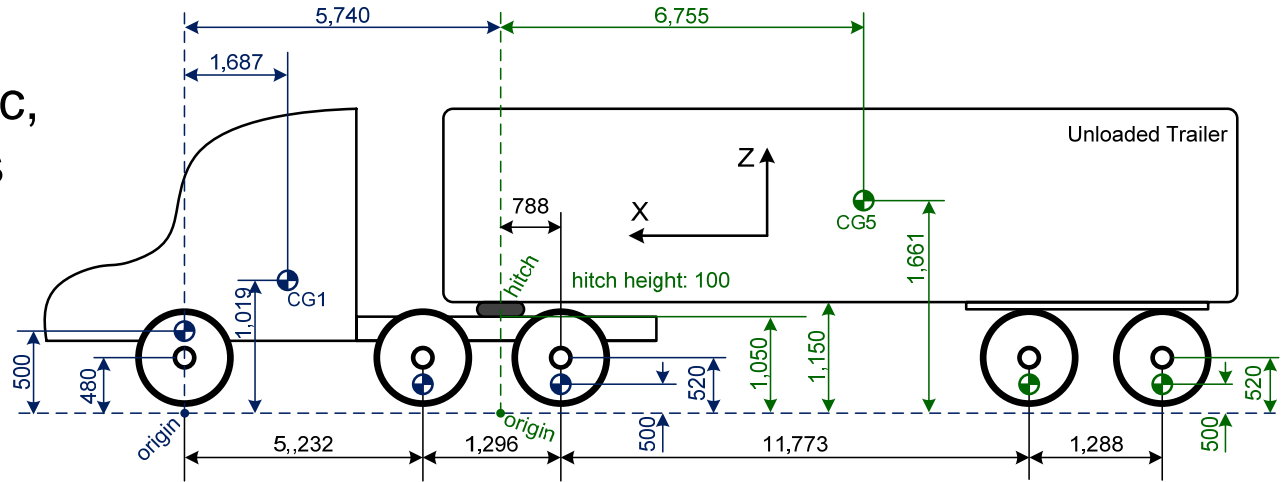
# System Design

- Truck dynamics with TruckSim computer simulation and Simulink for driver model
- System kinematics (speed, acceleration, yaw rate) sent to hardware wheel speeds were converted to actual hardware magnetic pick-ups
- ECU responds by sending braking signals, throttle disengagement, or engine brake
- Pressure measured from hardware, sent to TruckSim to determine brake torque from a 3-D look-up table (pressure-speed-torque)



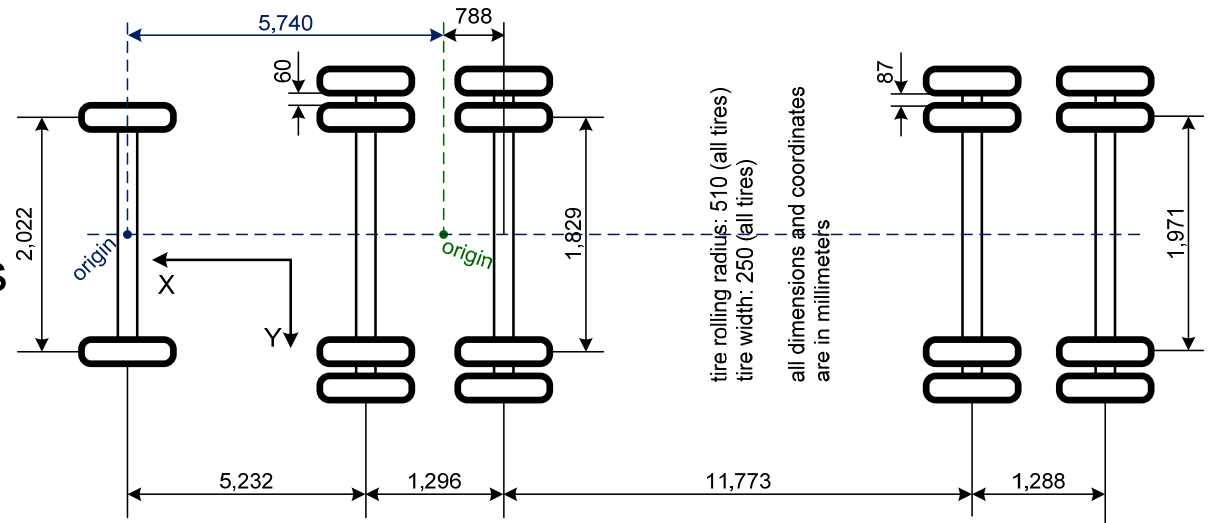
# Trucksim Model Based On Measured Heavy Tractor-trailer System

Mechanical, geometric, and inertial properties were measured



(a) CG Location of Tractor and Trailer (side view)

Torsional stiffness of chassis, fifth wheel were measured



(b) Wheelbases and Wheel Tracks (top view)

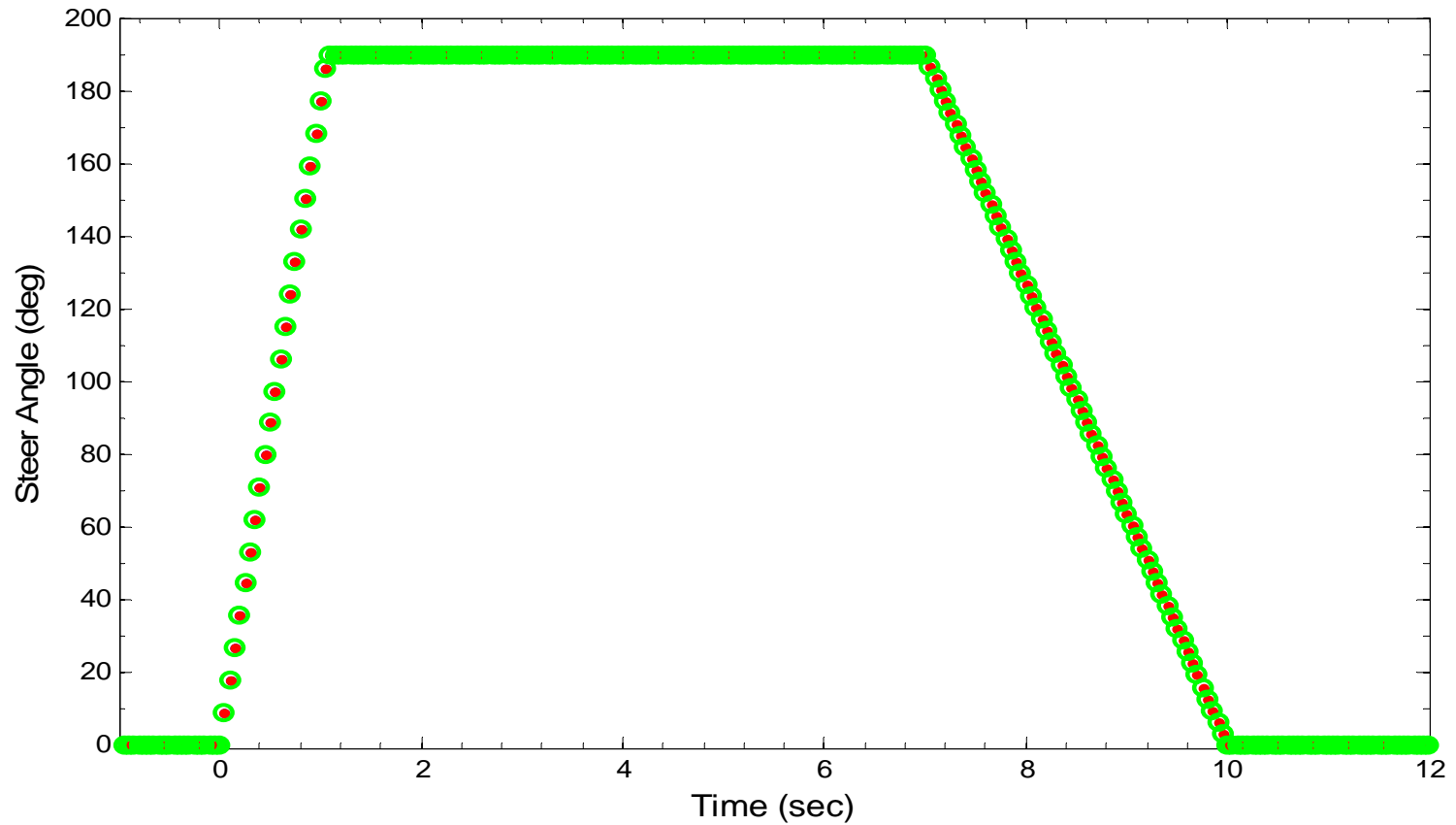
Tire forces and moments were measured

tire rolling radius: 510 (all tires)  
 tire width: 250 (all tires)  
 all dimensions and coordinates are in millimeters

# HiL Validation

- Simulation results compared to ramp steer maneuver (RSM) experimental data collected at NHTSA VRTC
- Maneuver speed was increased incrementally in HiL until rollover occurred
- HiL simulations are based on models with differences in tires, suspensions, and compliances used on the actual truck
  - Exact match between test data and simulation was not possible
  - Track data were useful for qualitatively checking the response of the HiL
  - Constant speed maintained by driver model vs. dropped throttle in experimental data.

# Ramp Steer Maneuver



# RSM Video



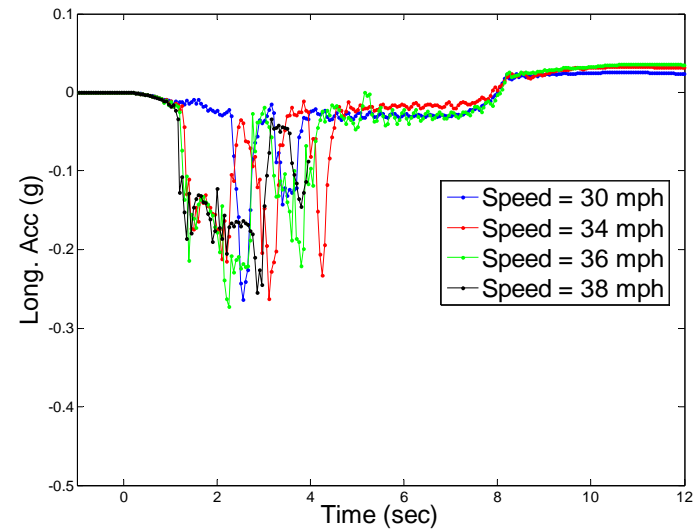
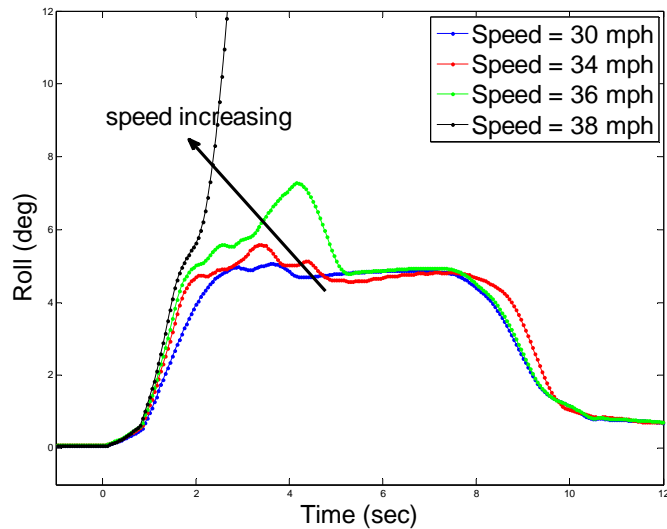
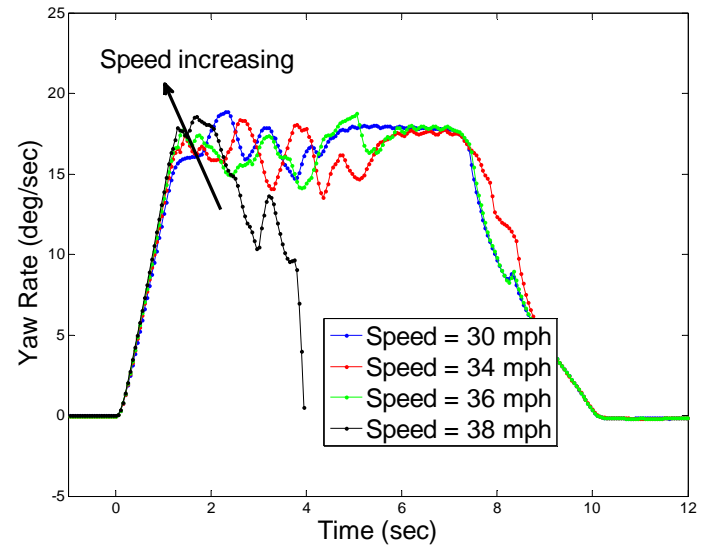
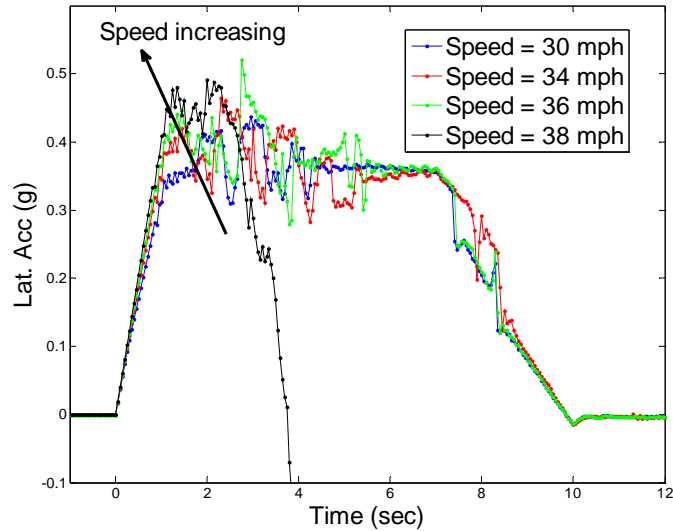
# HiL Simulations

- Simulations are valid for predicting the onset of rollovers (typically  $> 6^\circ$ )
- LTR (Load Transfer Ratio) is used for rollover potential

$$LTR = \frac{\left| \sum_{Left} F_{Ni} - \sum_{Right} F_{Ni} \right|}{\left| \sum_{Left} F_{Ni} + \sum_{Right} F_{Ni} \right|}$$

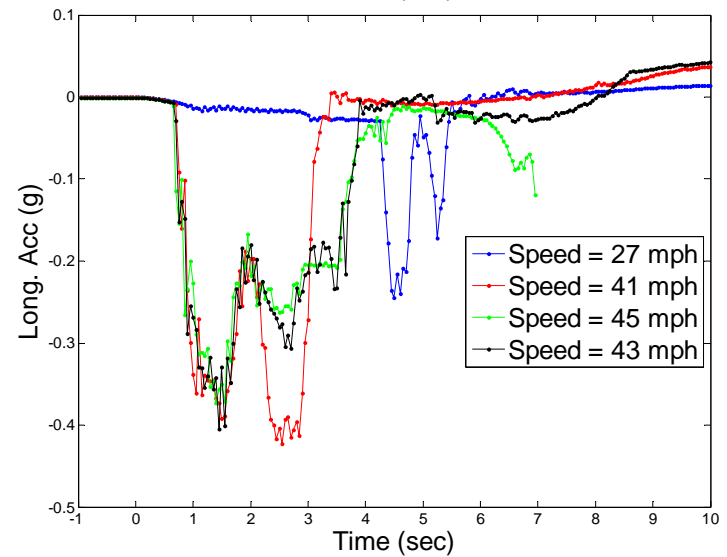
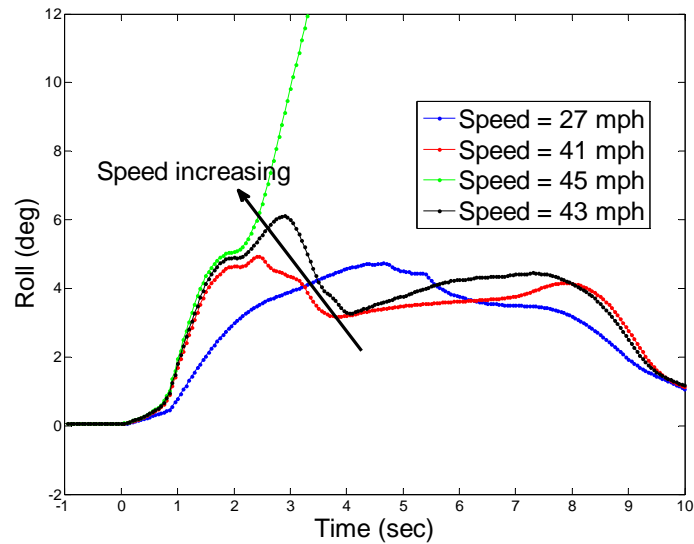
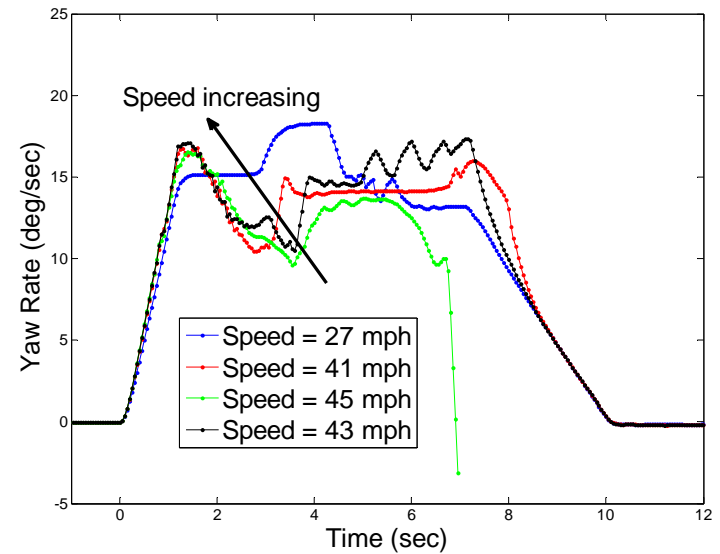
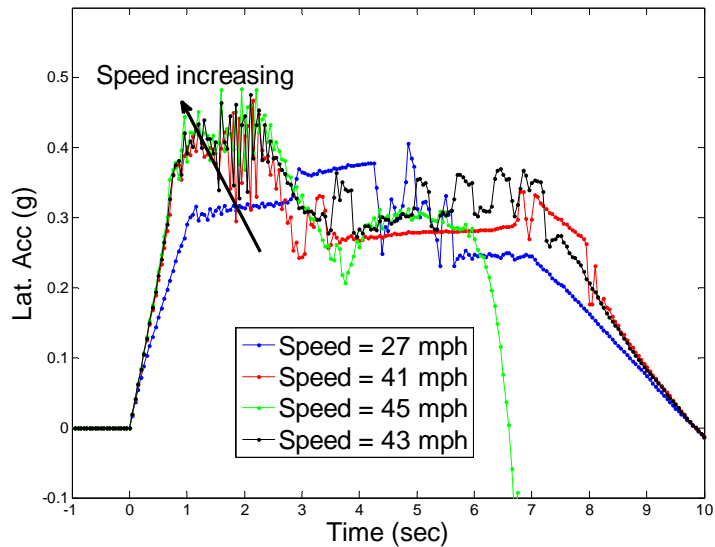
- $0 \leq LTR \leq 1$ , a value of 1 is a complete rollover, 0.9 is typically an onset of rollover

# RSC Simulation Results

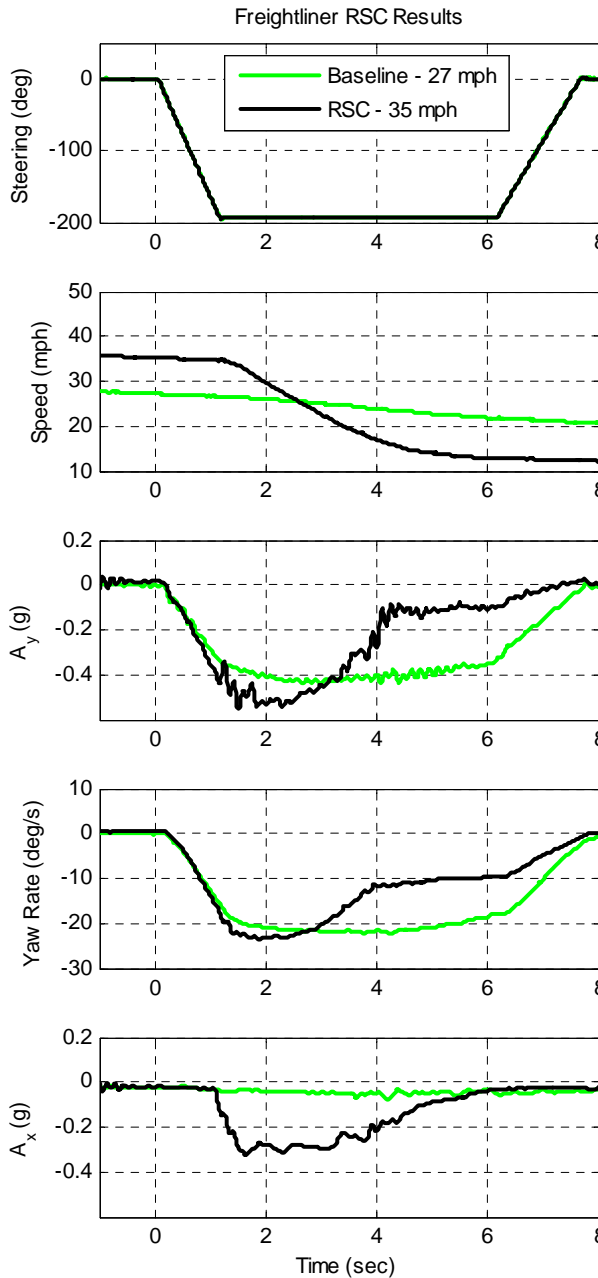




# ESC Simulation Results



# RSC-Baseline Experimental Results: 2006 Freightliner



Steering

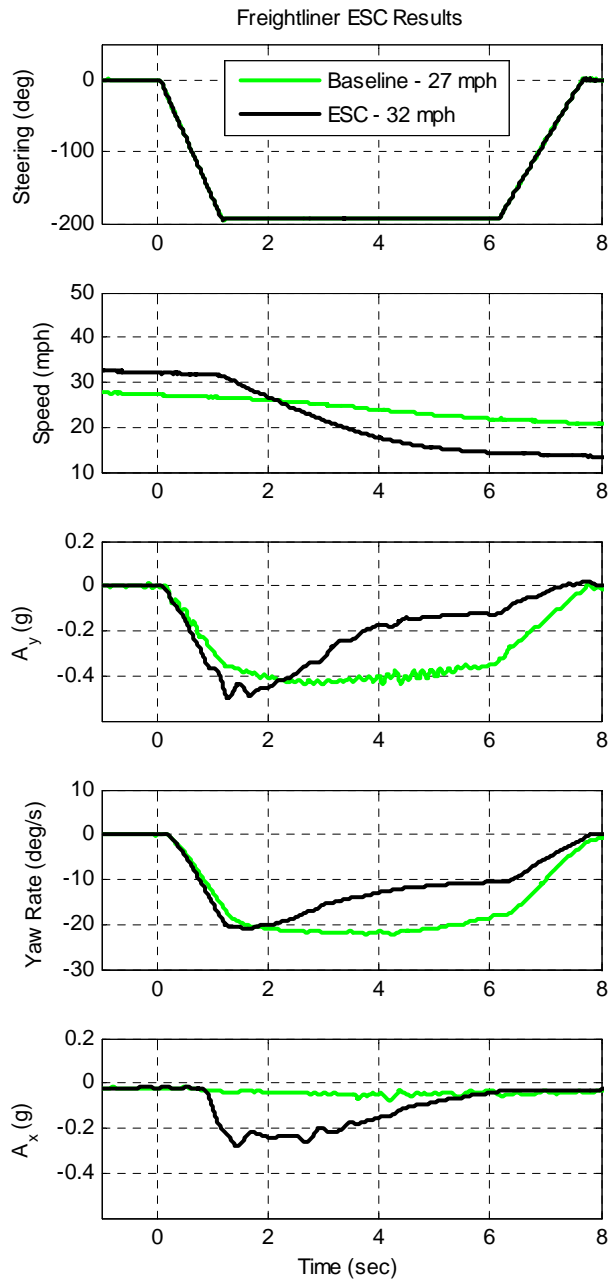
Speed

Lateral  
Acceleration

Yaw rate

Longitudinal  
Acceleration

# ESC-Baseline Experimental Results: 2006 Freightliner



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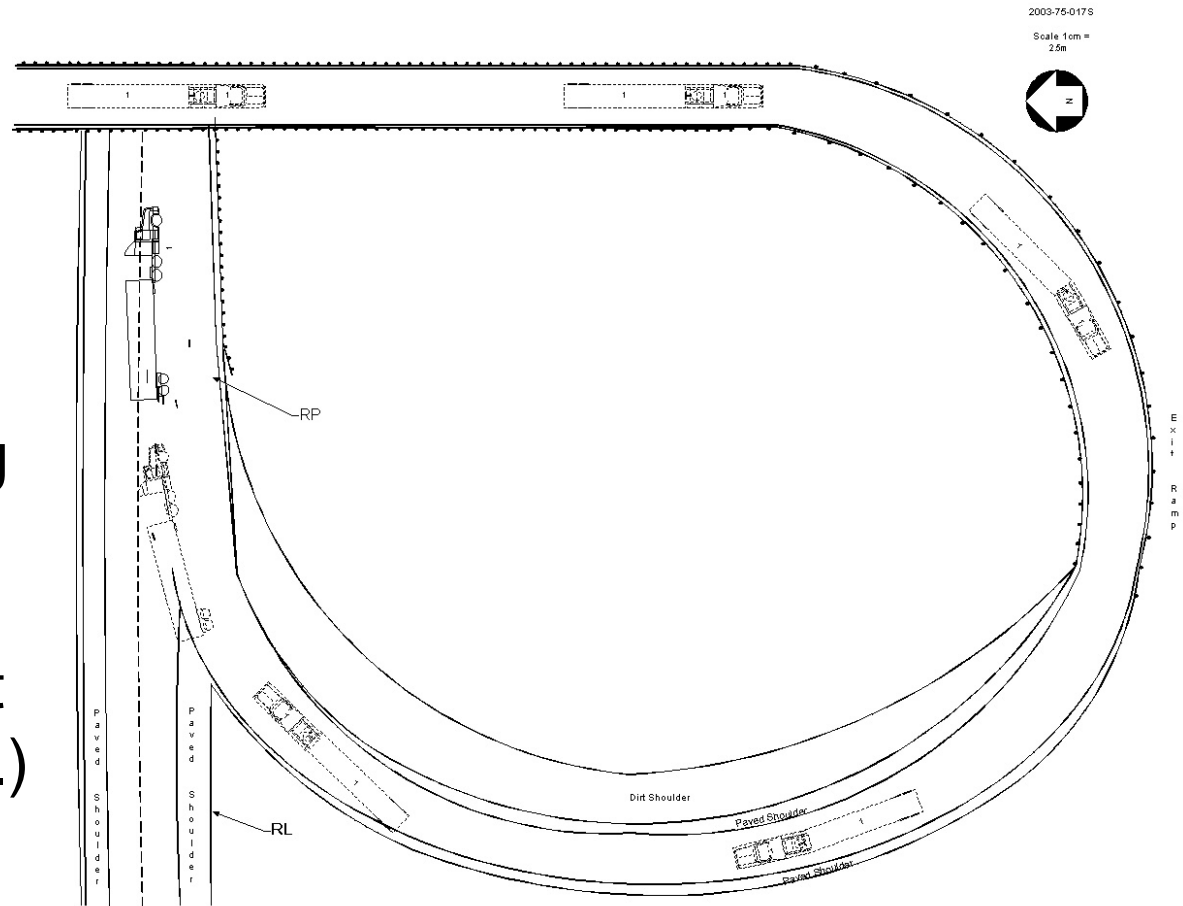
# Crash Data Review

- Large Truck Crash Causation Study (LTCCS)
- 963 Crash cases including 1128 vehicles
- 113 Rollover relevant
- Cases give detailed information about crash events
  - Scene diagram
  - Detailed narrative
  - Detailed coded crash events
  - Physical configuration of the vehicle (weights, lengths, axle count, cargo weight and type, etc.)
- Typical crash situations were selected for simulation



# Example LTCCS Rollover Case

Road curved  
Dry surface  
Cargo: loaded

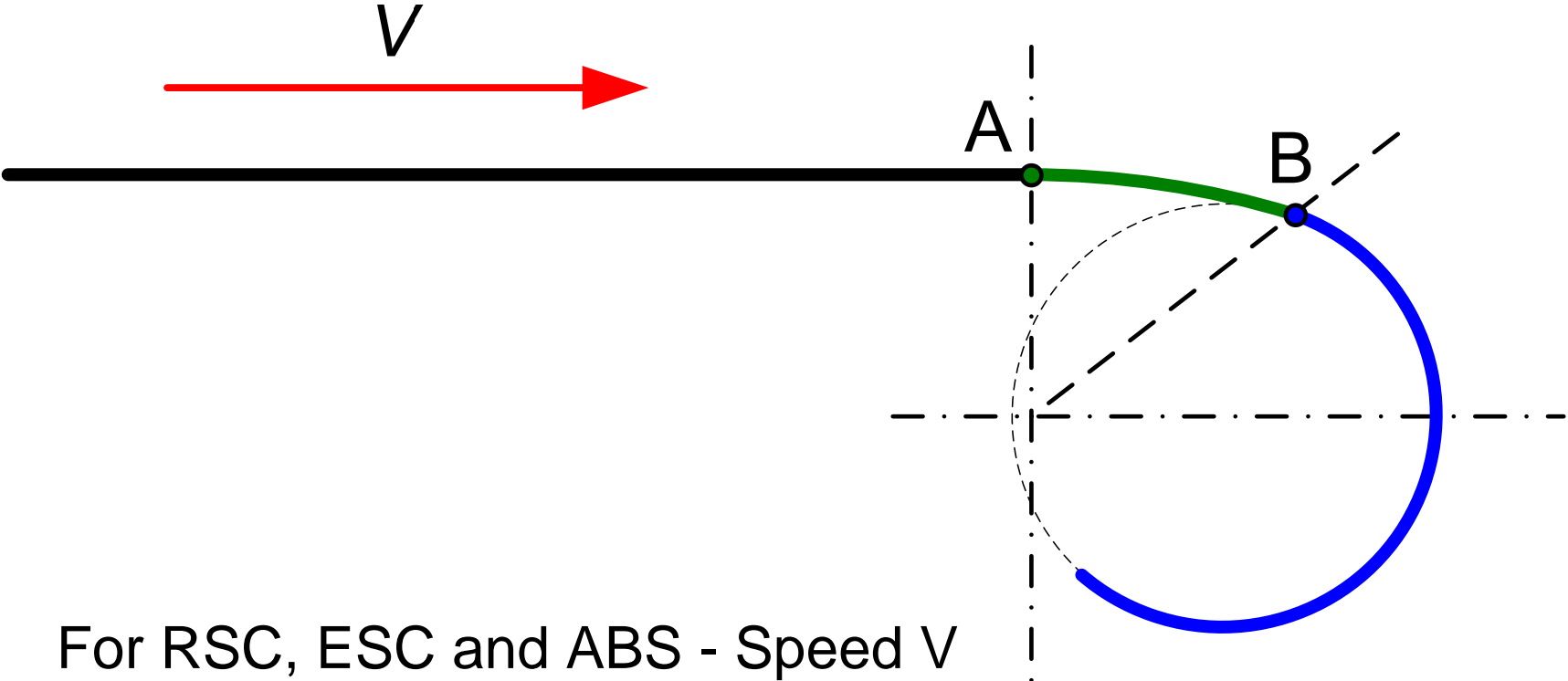
3-axle tractor pulling  
van trailer  
31,000 lbs cargo  
61,800 gross weight  
Speed: 40 mph (est.)



# Scenario Development

- Road Geometries Based on LTCCS Rollover Crashes
- LTCCS Mean Curve Radii Evaluated
  - Curves with radii  $< 100$  m  mean value 68 m
  - Curves with radii  $> 100$  m  mean value 227 m
- Rollover Scenarios
  - Four scenarios based on road geometries with curvatures
  - Lane change on a straight road
    - Driver changes lanes aggressively to avoid a slow or stopped vehicle
  - Constant speed maneuvers

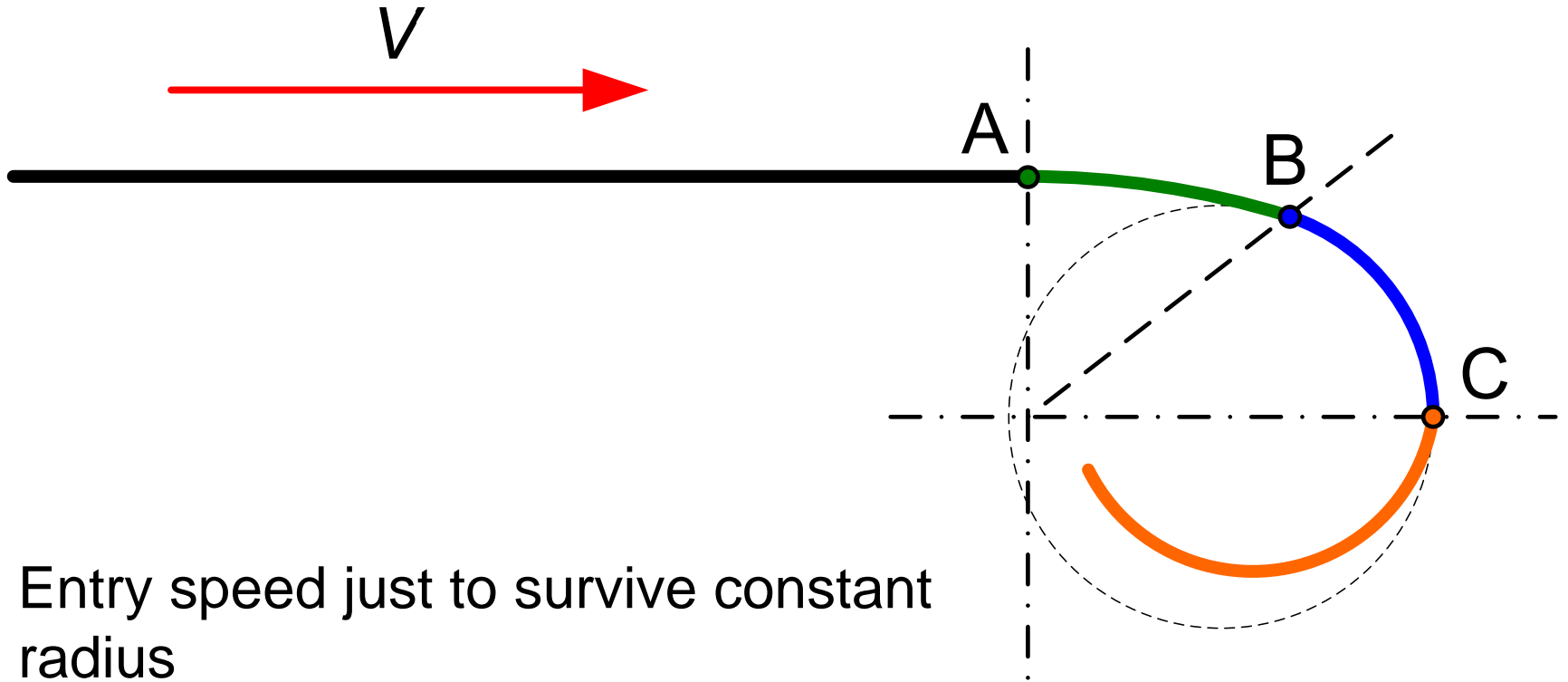
# Entry to Freeway Exit Ramp: (68 and 227 m)



For RSC, ESC and ABS - Speed  $V$  is increased until rollover

**Rollover Criteria:  $V$**

# Constant Radius to Diminishing Curve

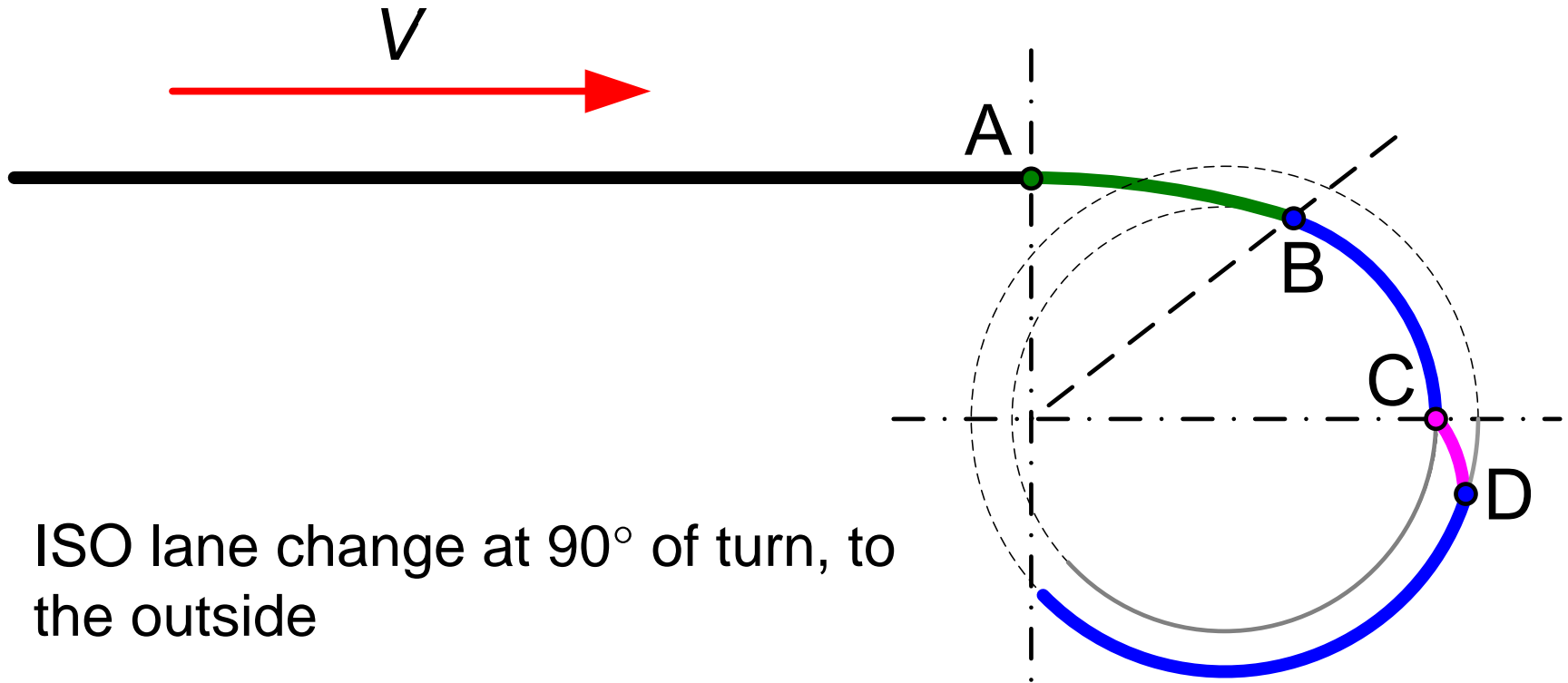


Entry speed just to survive constant radius

**Criteria: position after point C.**



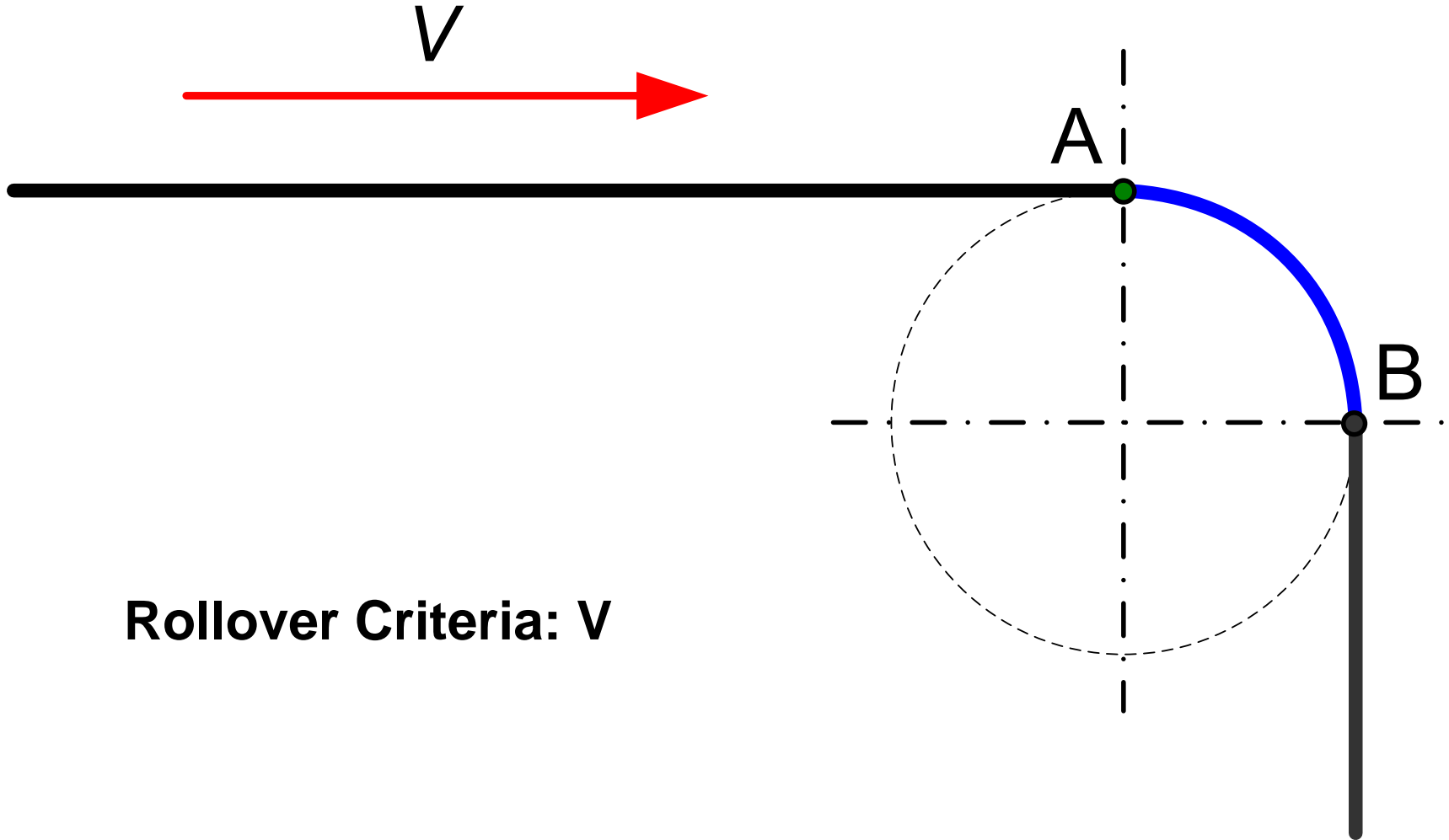
# Lane Change on Exit Ramp



ISO lane change at  $90^\circ$  of turn, to the outside

**Rollover Criteria:  $V$**

# Turn at an Intersection: radius is 20 m

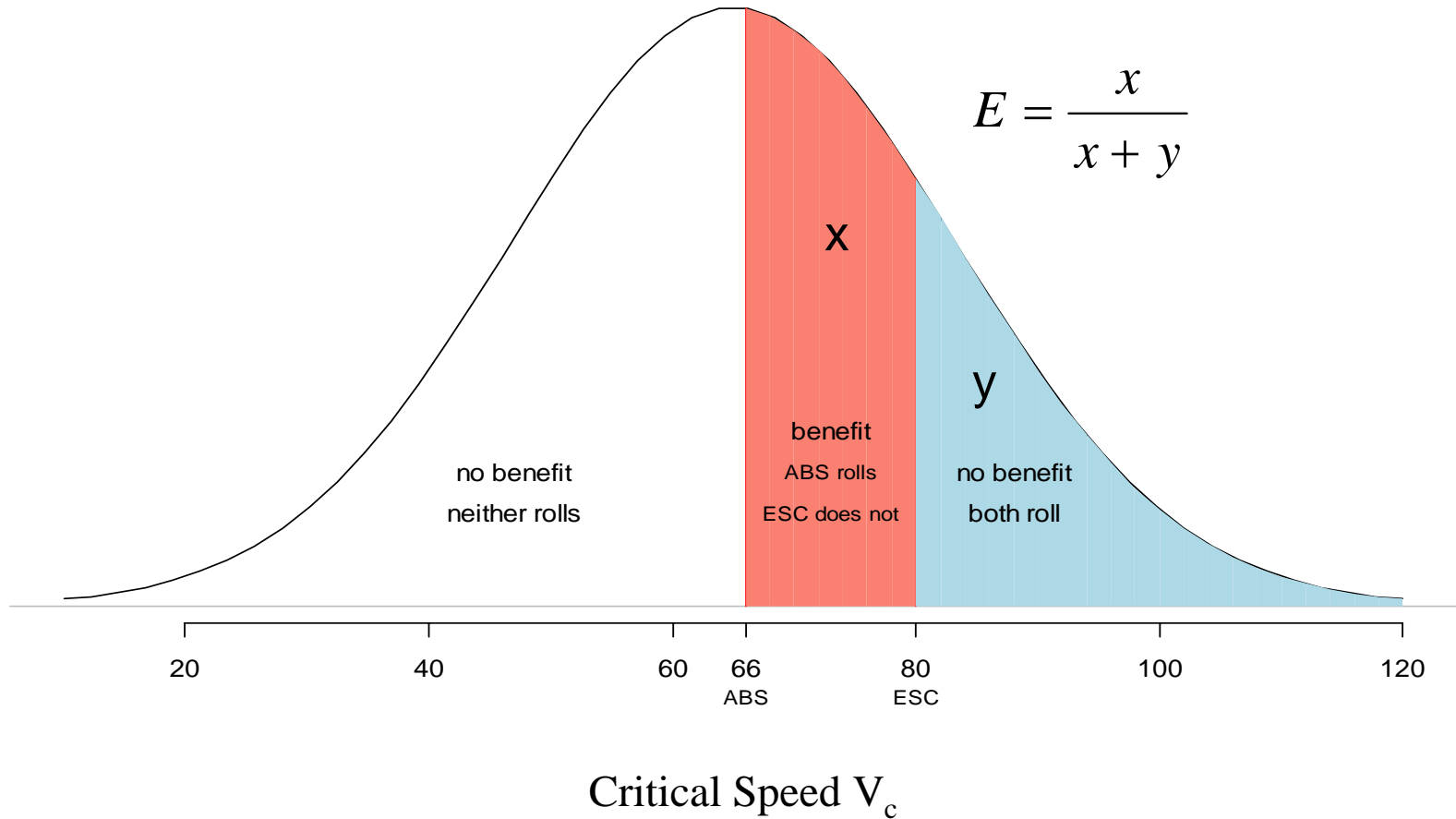


**Rollover Criteria:  $V$**

# Determining System Effectiveness

- Critical Speed  $V_c$  - highest speed for which no rollover occurs
- $V_c$  was determined for ABS, RSC, and ESC
- Effectiveness calculated as the area under the distribution curve of  $V_c$

# Calculating Effectiveness



# Linking Effectiveness to Potential Safety Benefits

- Scenarios derived from pre-crash events
- Populations from national crash databases are associated for each scenario
- Effectiveness for a scenario is expressed in terms of a probability of a crash
  - Prevention ratio

# Benefit Equation

B = Benefit in Terms of Reduced Number of Crashes

$$B = [P_{wo}(C) - P_w(C)] \times \text{Exposure}$$

$P_{wo}(C)$  = Probability of Crash Without Technology

$P_w(C)$  = Probability of Crash With Technology

Exposure = All Trucks in the Population

# Benefit Equation For a Given Crash Scenario, S

$$B = N_{wo} \times P_{wo}(S | C) \times \left[ 1 - \frac{P_w(C | S)}{P_{wo}(C | S)} \right]$$

From Crash Data

From HIL simulation

$1 - (\text{Prevention ratio}) = E$

# Summary

- HiL system developed at UMTRI provided an objective means for determining RSC and ESC effectiveness
- Effectiveness measures were used to determine system benefits by linking crash data from national databases
- Methodology provided a means to determine safety benefits for a technology with limited exposure data



# Upcoming Publications

- Paper in 21st International Technical Conference on the Enhanced Safety of Vehicles Conference (ESV) - International Congress Center Stuttgart, Germany, June 15–18, 2009.
- NHTSA Final Report on safety benefits of stability control available in late 2009.



For Further  
Information

Website:

[www.nhtsa.gov](http://www.nhtsa.gov)

Thank You

