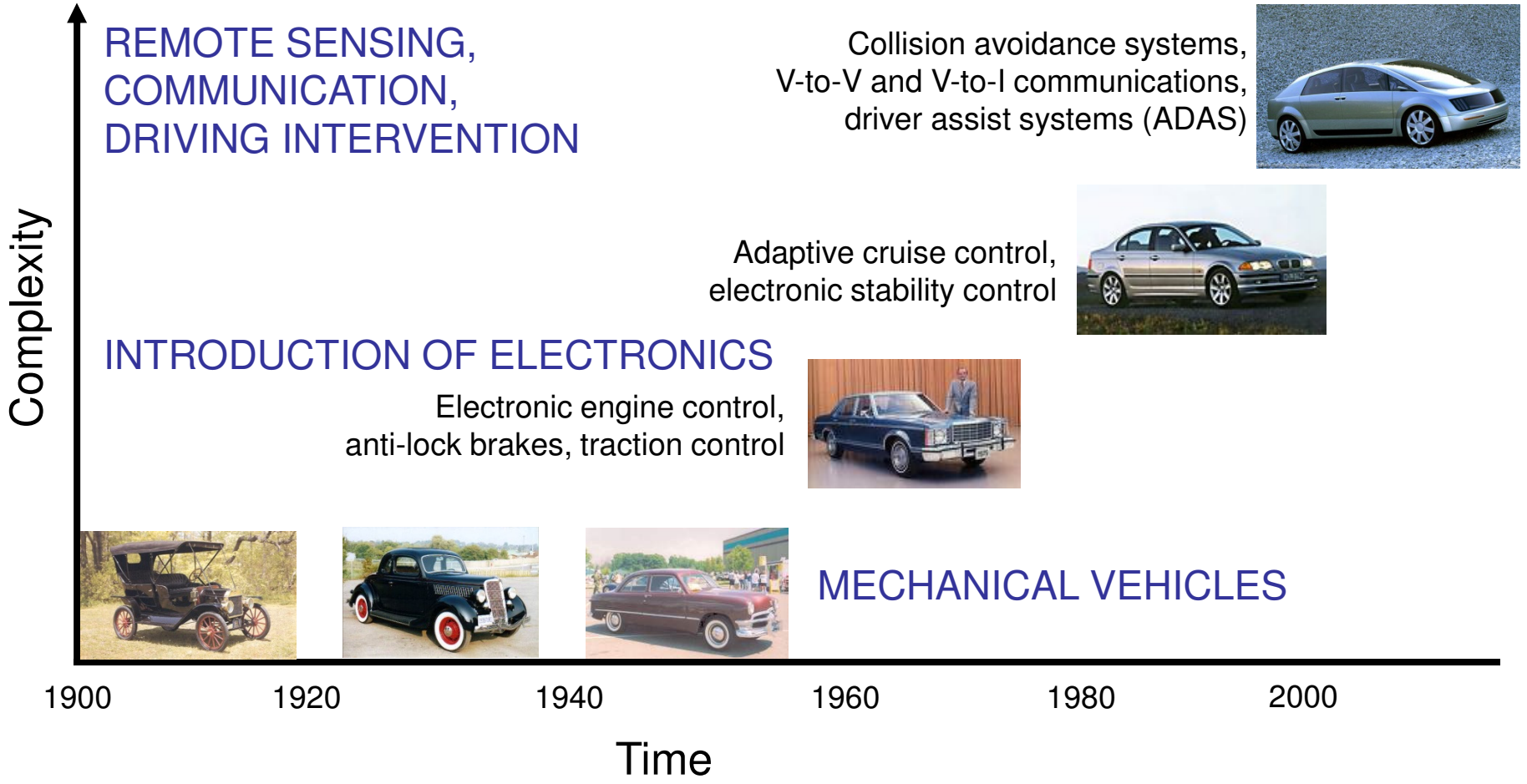
Overview of Current Vehicle Dynamics

Thomas D. Gillespie, Ph.D.

Mechanical Simulation Corp.

Evolution of the Automobile



Mechanical Complexity

- Mechanical complexity has grown exponentially
- First cars had about 2000 parts
- Modern cars have about 14,000

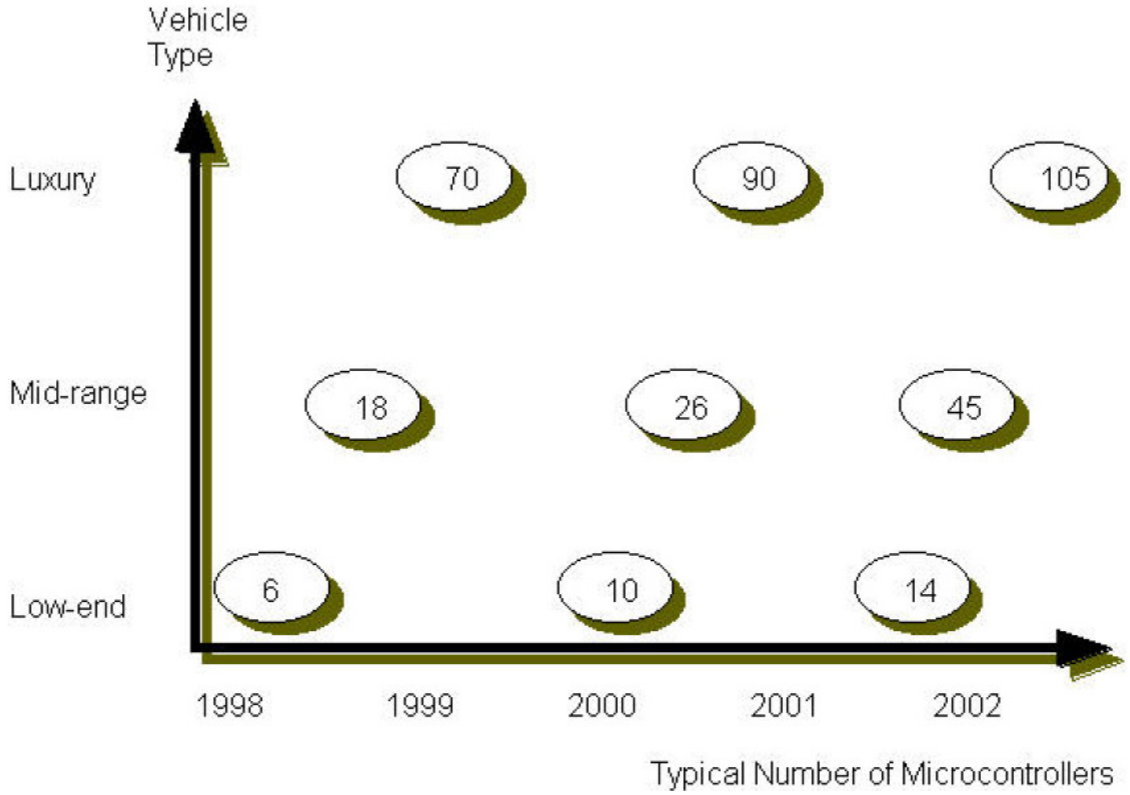
1966 Mustang

2003 Mustang

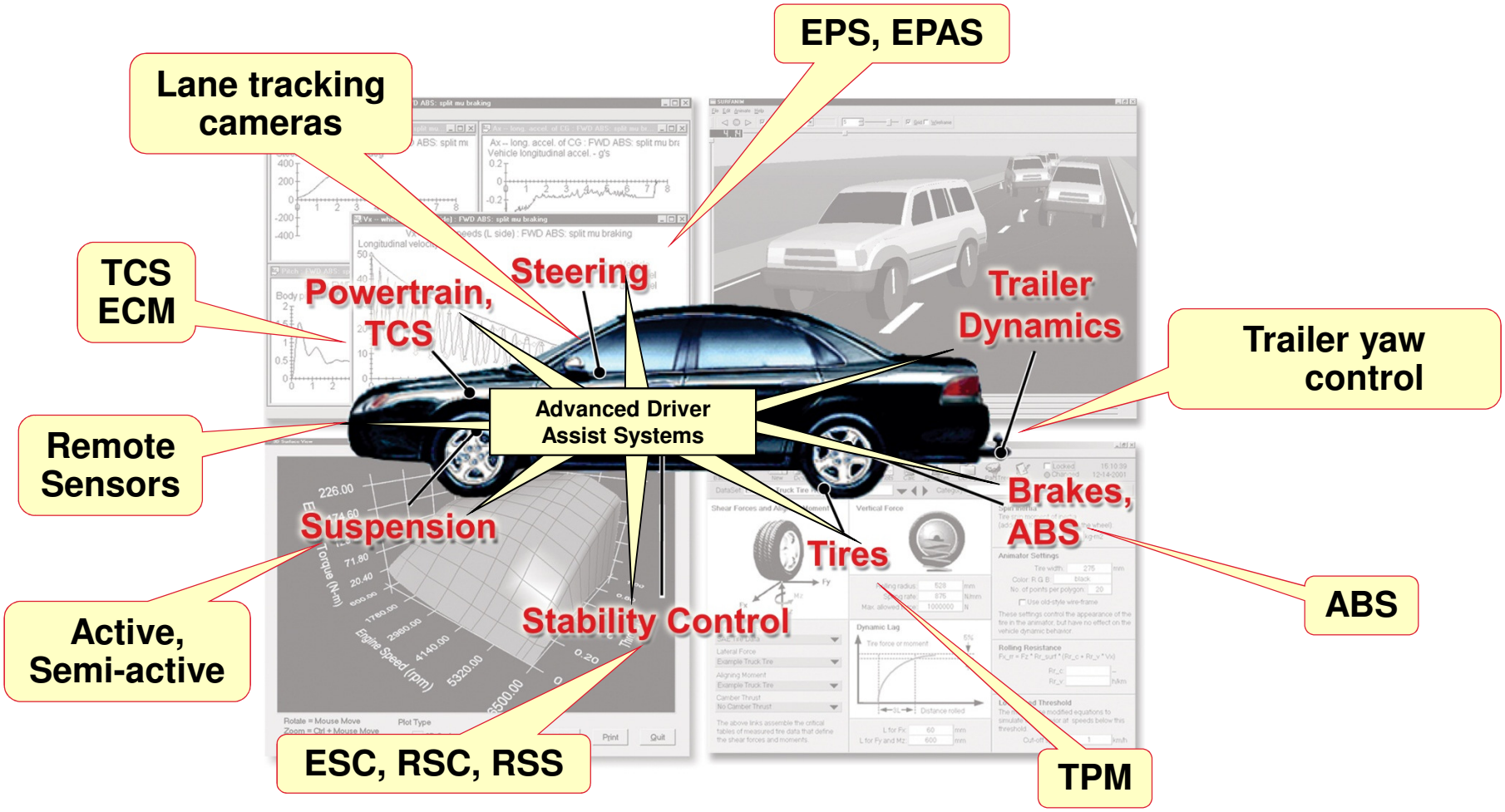
Electronic Complexity

- Electronics augment mechanical systems for
  - Sensing
  - Computing
  - Control
- Result:
  - ECUs proliferate
- Functions of multiple ECUs need to be coordinated
- Many influence vehicle dynamic behavior

Growth in Microcontroller Use



Electronics Influence All Vehicle Dynamics



Functional Complexity

Larry Burns, General Motors, “Automotive Trends and Opportunities”

ABS – The Paradigm Shift with Electronics

- 1970 -- Introduction of Anti-Lock Brake Systems
  - Pre ABS Control Paradigm

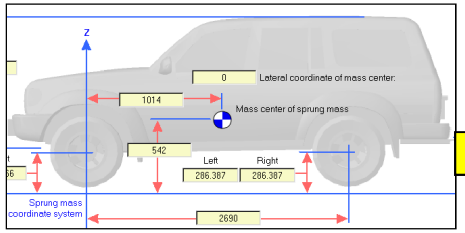
    Brakes apply in accordance with the pressure on the brake pedal
  - Post-ABS Control Paradigm

    Brakes may be released for brief periods during braking maneuver

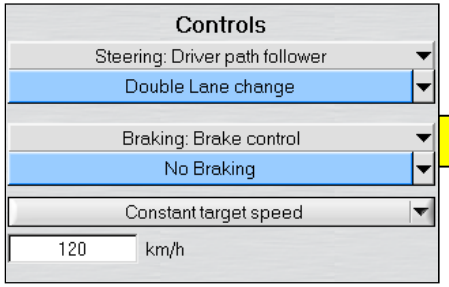
    "There are times when the controller knows better than the driver"
- The ability to sense, compute and actuate means we can change the behavior of the car to suit driving conditions
- Places new and greater responsibility on the automotive engineer to
  - Design for *known* driving situations
  - Have tolerance for the *unknown*
- The need for testing increased dramatically
- Vehicle dynamic simulation provided the solution

What is Vehicle Dynamics Simulation?

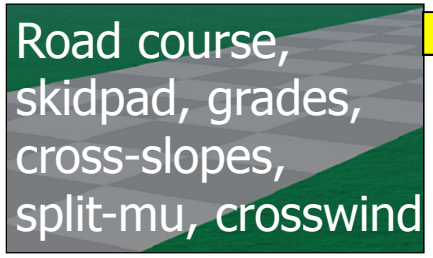
Vehicle Data



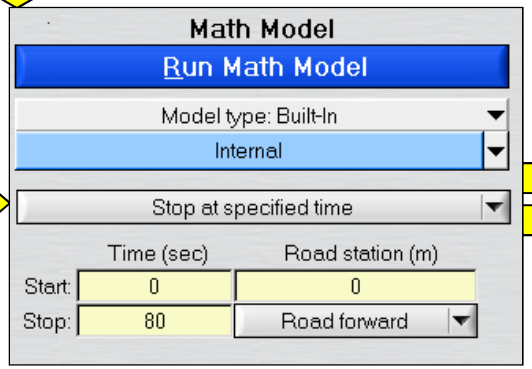
Maneuver



Road and Wind

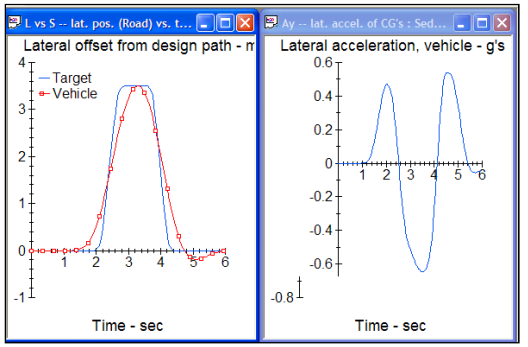


Math Model



Animation

Plots



Where is Simulation Used?

Car*Sim* Example

Product Launch

Marketing Tools - Animations, driving simulators

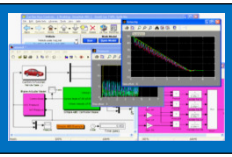
Vehicle Testing

Proving Ground Optimization
Regulatory certification

Component Testing

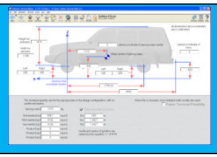
Test with Car*Sim* and Hardware in the Loop (HIL)

Controls Development



Test with Car*Sim* and other Software in the Loop (SIL)

System Definition



Simulate with Car*Sim*
Answers to "What if…?"

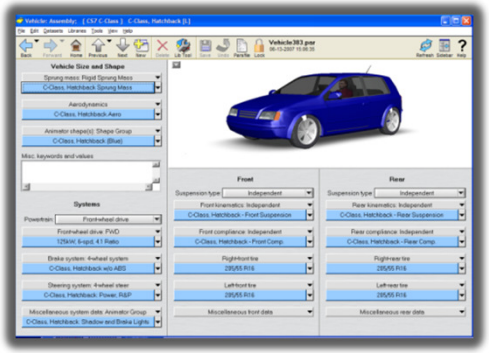
Vehicle Definition

Vehicle Requirements, Capabilities, and Capacities

Aftermarket

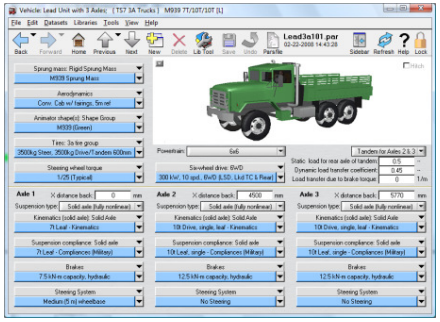
CarSim

- Cars, light trucks, SUVs, race cars
- CarSim + Trailer option
- 25 example vehicles
- 150+ test examples



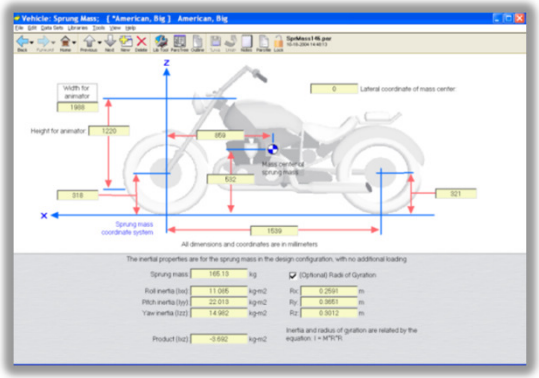
TruckSim

- Combination vehicles (trucks and trailers)
- Dual tires, multiple axles
- 12 sample truck-trailer-axle configurations
- 100+ test examples
- Custom configurations available



BikeSim

- Motorcycle dynamics
- Touring, racing, motocross, and scooters
- 10 sample bikes
- 40+ test examples



The Car*Sim* Vehicle Family

- Simulate immediately – choose from 25 generic vehicles

A-class Hatchback

B-class Hatchback, Sports car

C-class Hatchback

D-class Minivan, Sedan, SUV

E-class Sedan, SUV

F-class Sedan

F3

3-Wheeler

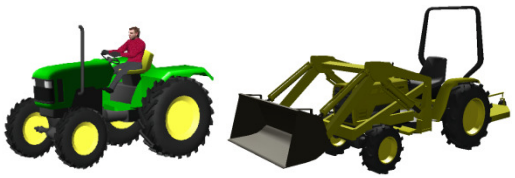
GT

Euro Van

Pickup

Mini Truck

Trailers

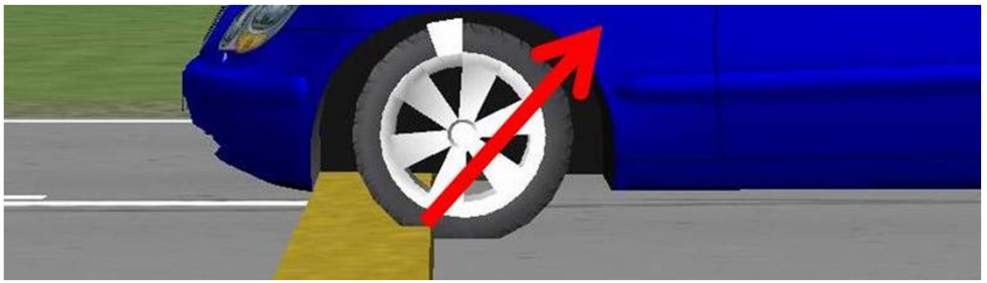


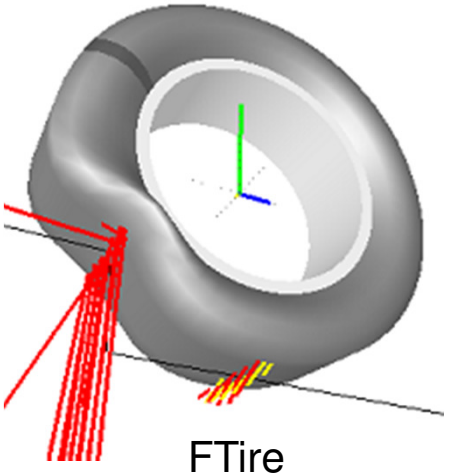
Tractors

Tire Modeling Options in Car*Sim*

- Built-in combined slip model with enhancements
- Built-in Pacejka 5.2
- Built-in MF-Tyre (licensed from TNO)
- Support* for MF-Swift
- Support* for FTire – Flexible Ring Tire Model
  - 3D nonlinear in-plane and out-of-plane tire model
  - Designed for ride/comfort simulation

*Separate license required





FTire

How is Simulation Used?

- Simulation tools like Car*Sim* can be used **Stand Alone**,

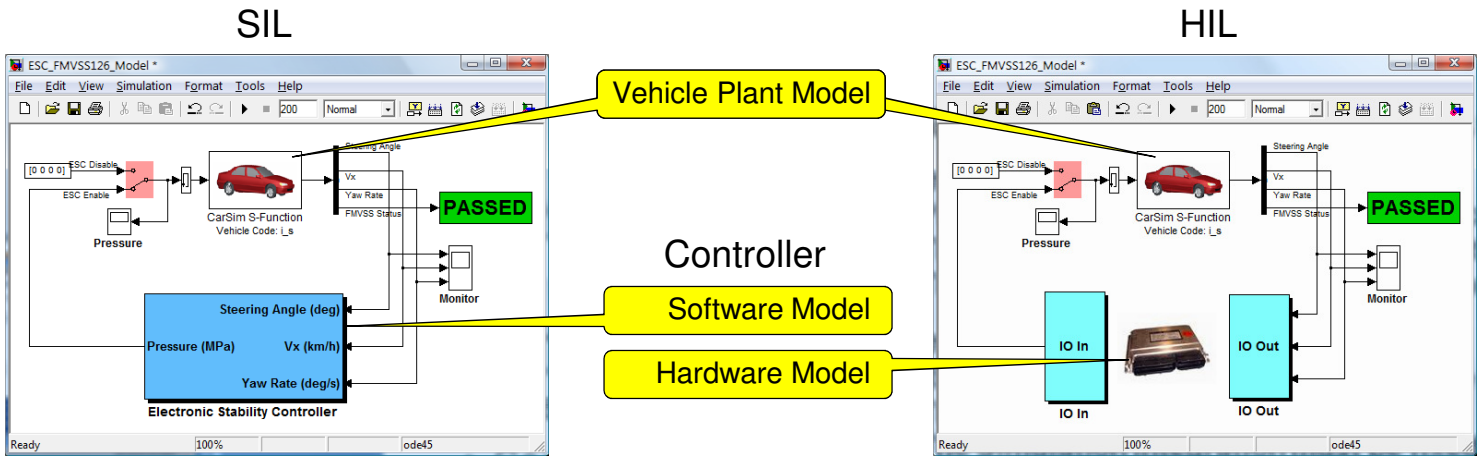
and with:

Software in the Loop (SIL)

- Software controller model
- CarSim vehicle and environment
- No timing control
- Runs as fast as possible
- Full “virtual” test

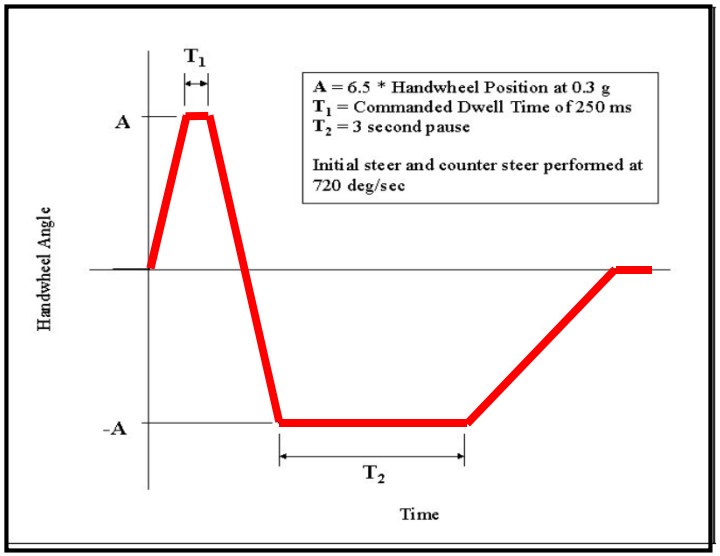
Hardware in the Loop (HIL)

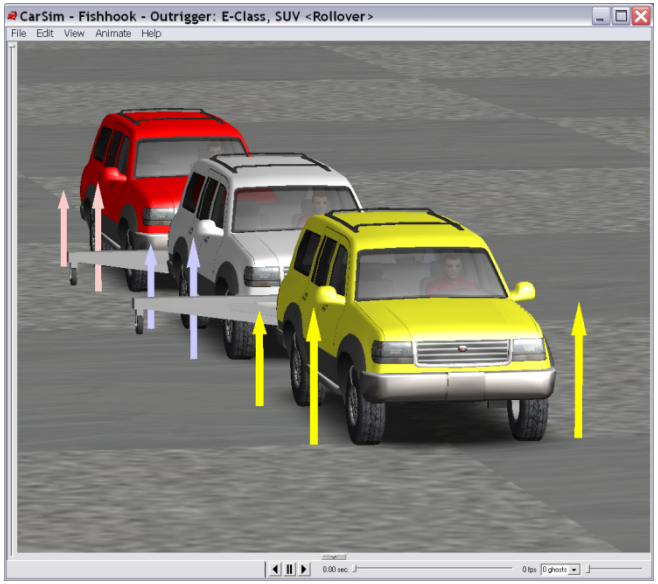
- Hardware controller (ECUs, actuators)
- CarSim vehicle and environment
- Real time operating system
- Integration time step must be fixed
- Partial “virtual” test



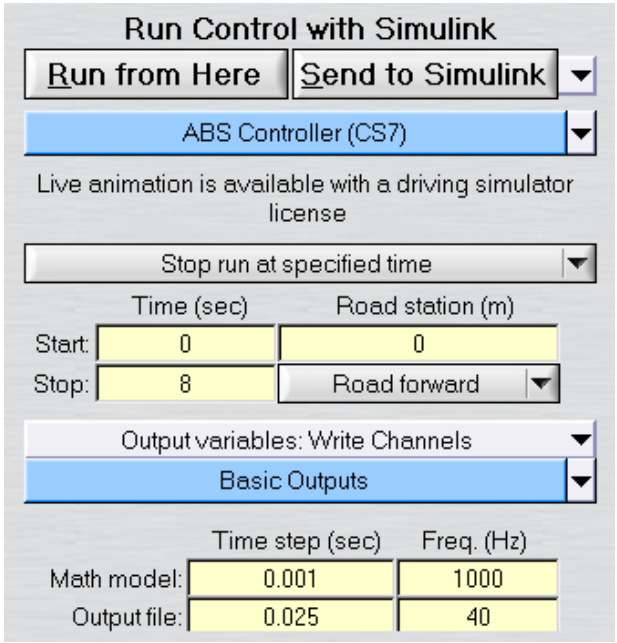
Stand Alone Example – Regulatory Compliance

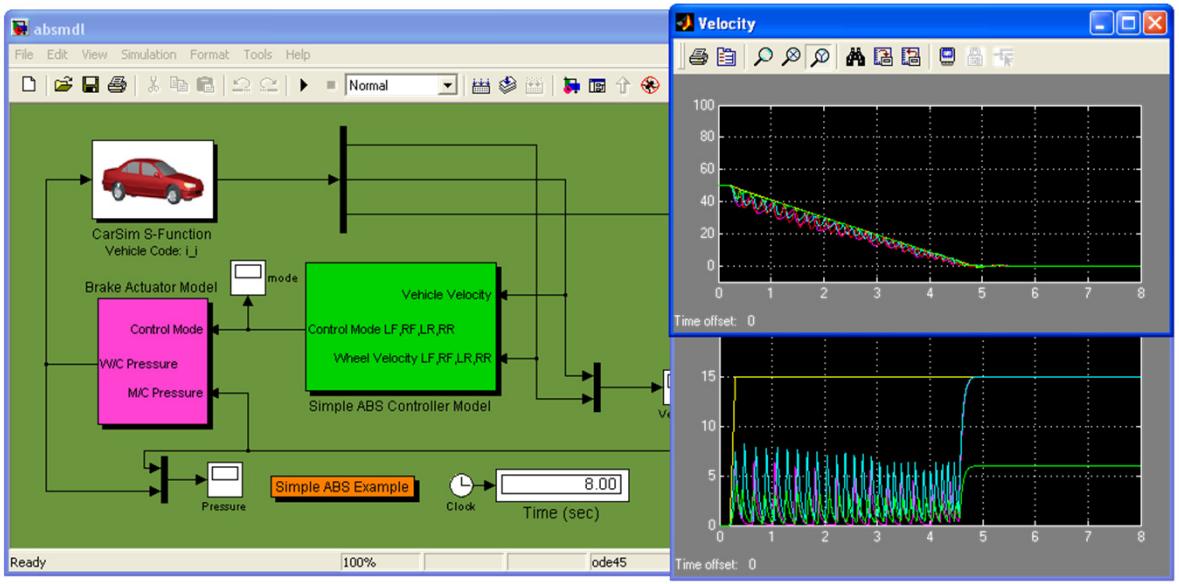
- U.S. Government regulates rollover behavior with Fishhook test
  - Requires steering robot for precise control input
  - Tests at multiple speeds and loads
- Virtual tests are easily conducted in CarSim (and virtually free)
- Evaluate and certify Fishhook compliance at early design stage





Simulink – A Popular Choice for SIL



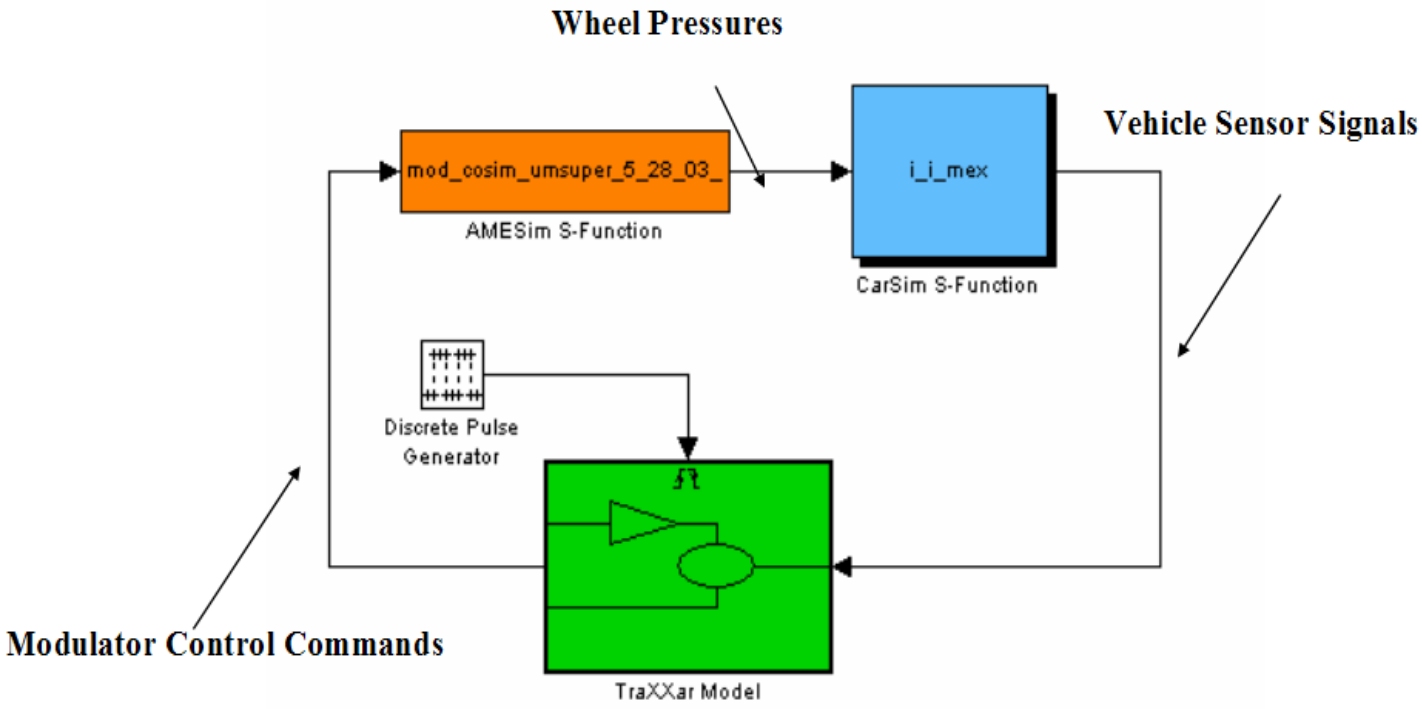


- Simulink models electronic controllers for CarSim (e.g., ABS, ESC)
- CarSim models are S-functions in Simulink
- Run Simulink from CarSim or CarSim from Simulink
- Batch run from either environment for optimization, DOE, etc.

SIL Example – Traction Control

Delphi Co-simulation in Development of TraXXar

Simulink® used for both the Traxxar® model and interface to AMESim® and CarSim®

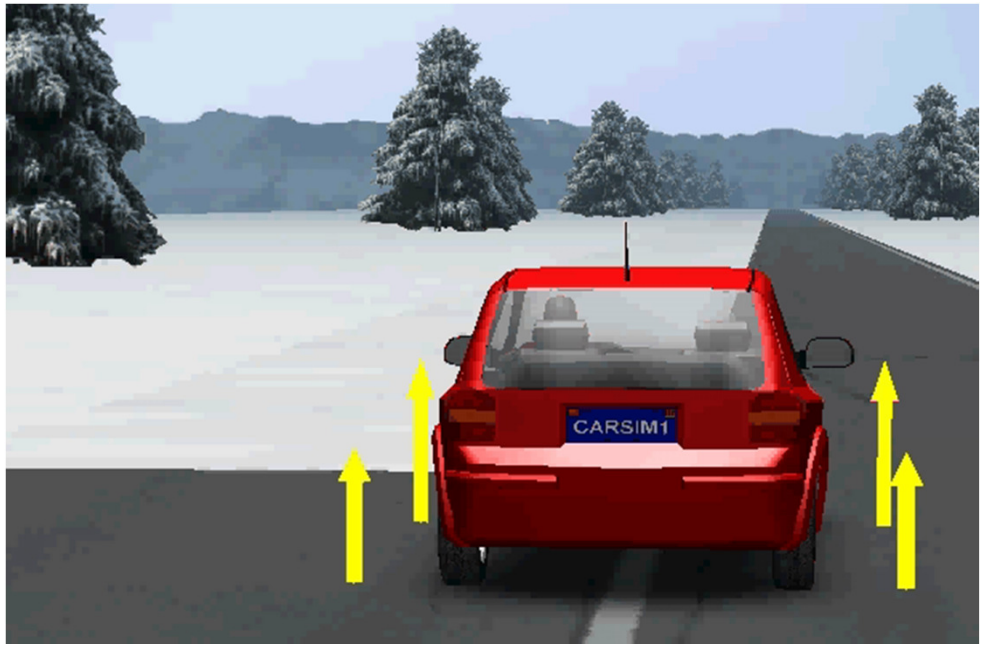


Bryan Fulmer, Delphi, "Using CarSim for Co-simulation of Chassis Control Systems"

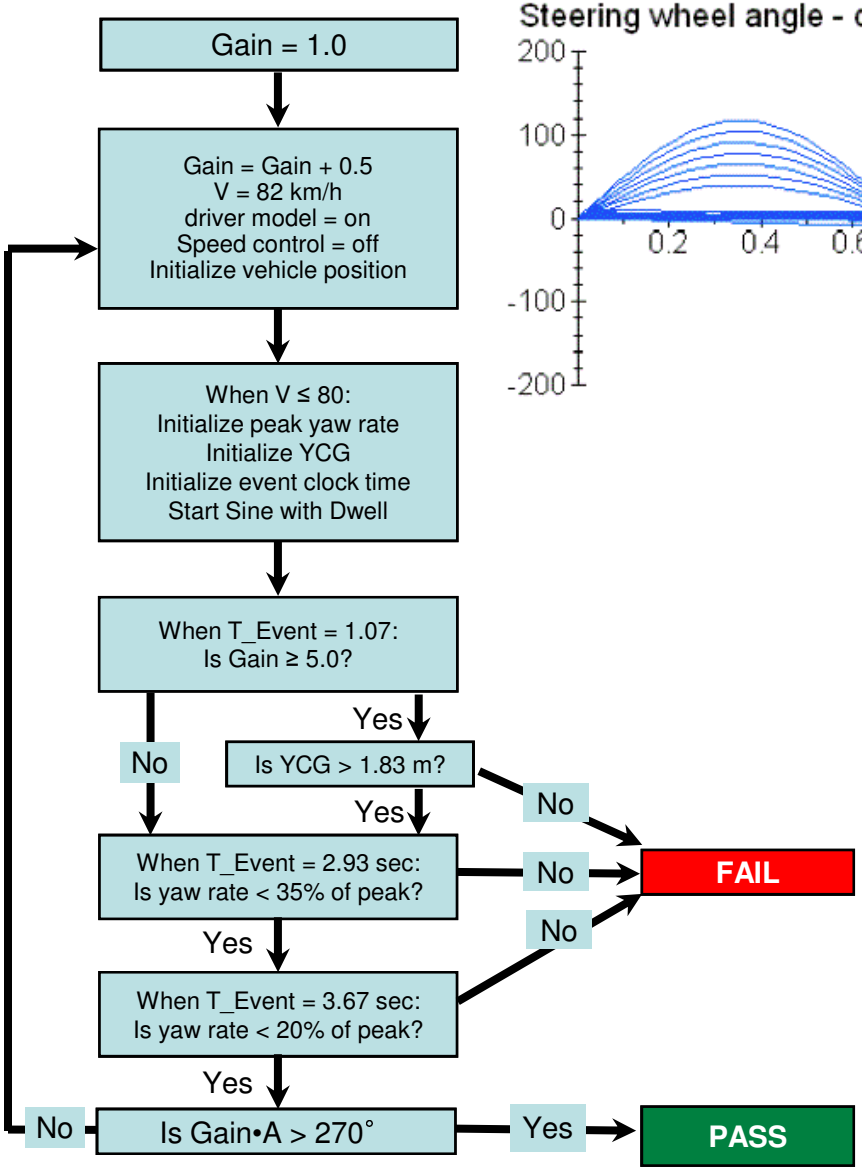
SIL Example – ABS in Simulink

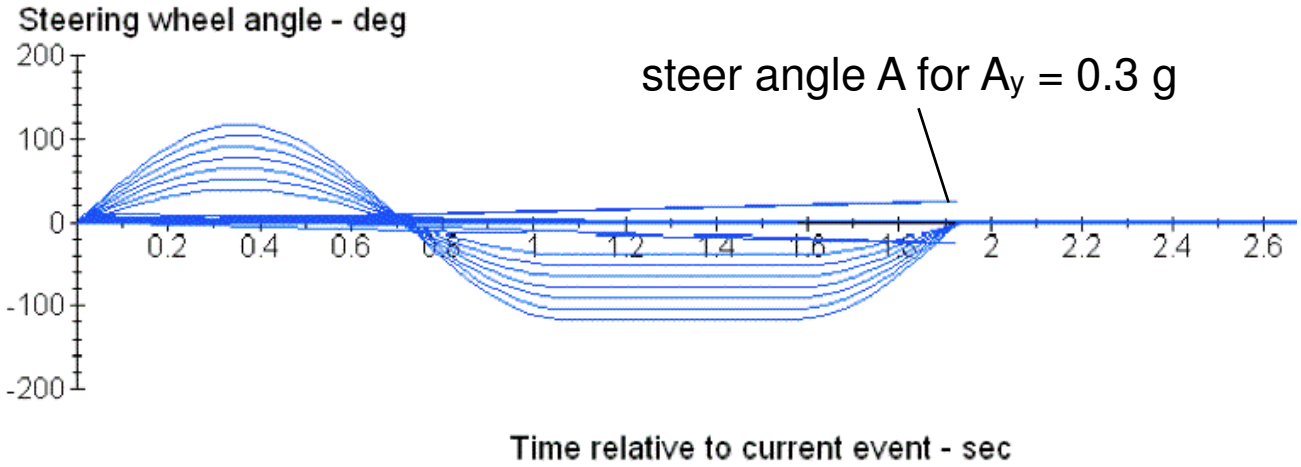
- **Issues**
  - Wide variety of variables
    - Inconsistent friction
    - Hills
    - Curves
    - Payloads
    - Driver behaviors
    - Climates
  - Requires complete vehicle

- **CarSim Solution**
  - Integrate ABS with Simulink
  - Optimize ABS algorithms
  - Simulation battery of tests



SIL Example – Complex Stability Test

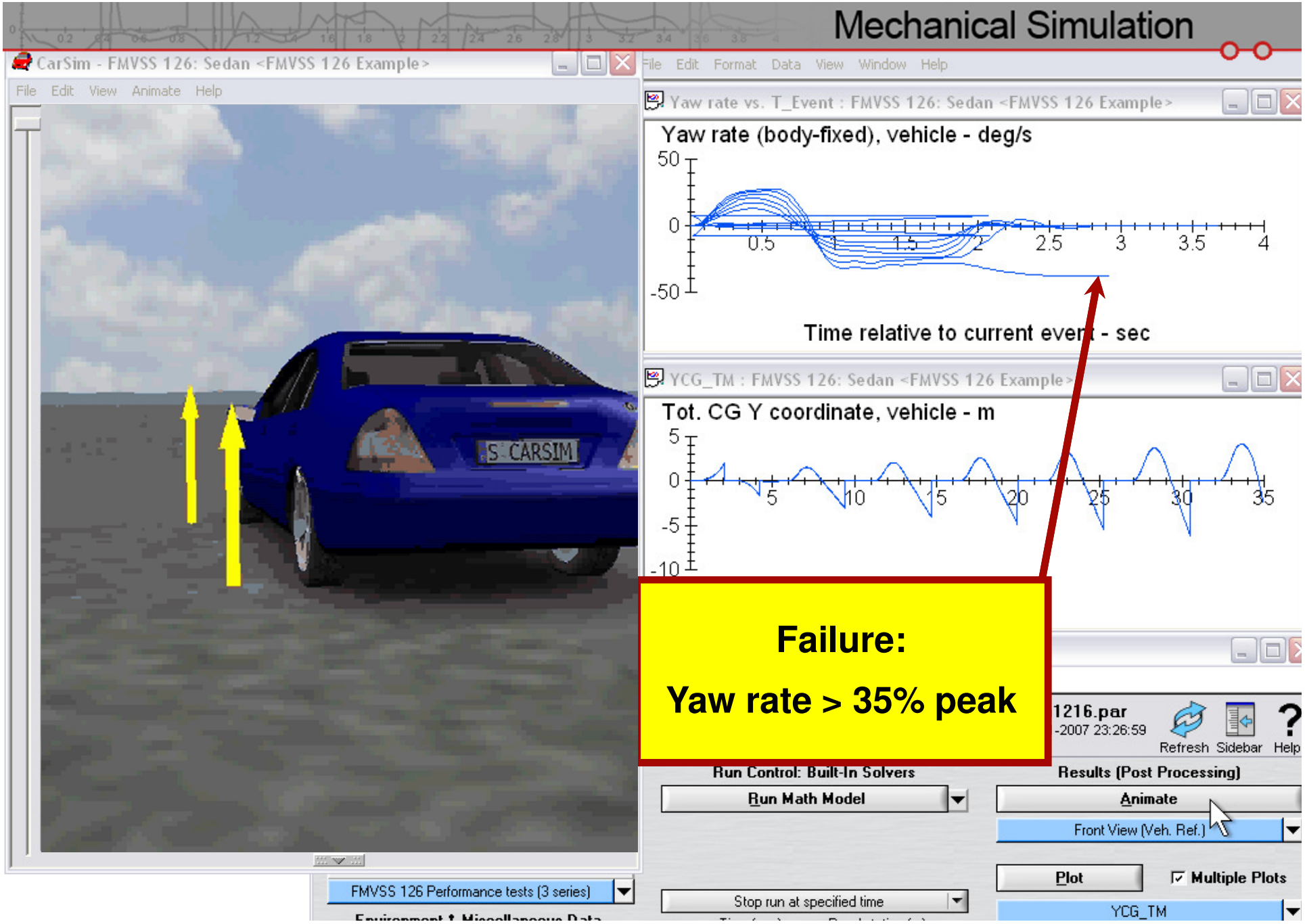




FMVSS 126 Test Procedure

- Run tests to find steer for A_y = ±0.3 g at 80 km/h
- Run series of “sine with dwell tests”
- Check lateral position (T = 1.07)
- Compare yaw rate at two times to peak yaw rate
- Test until steer > 270°

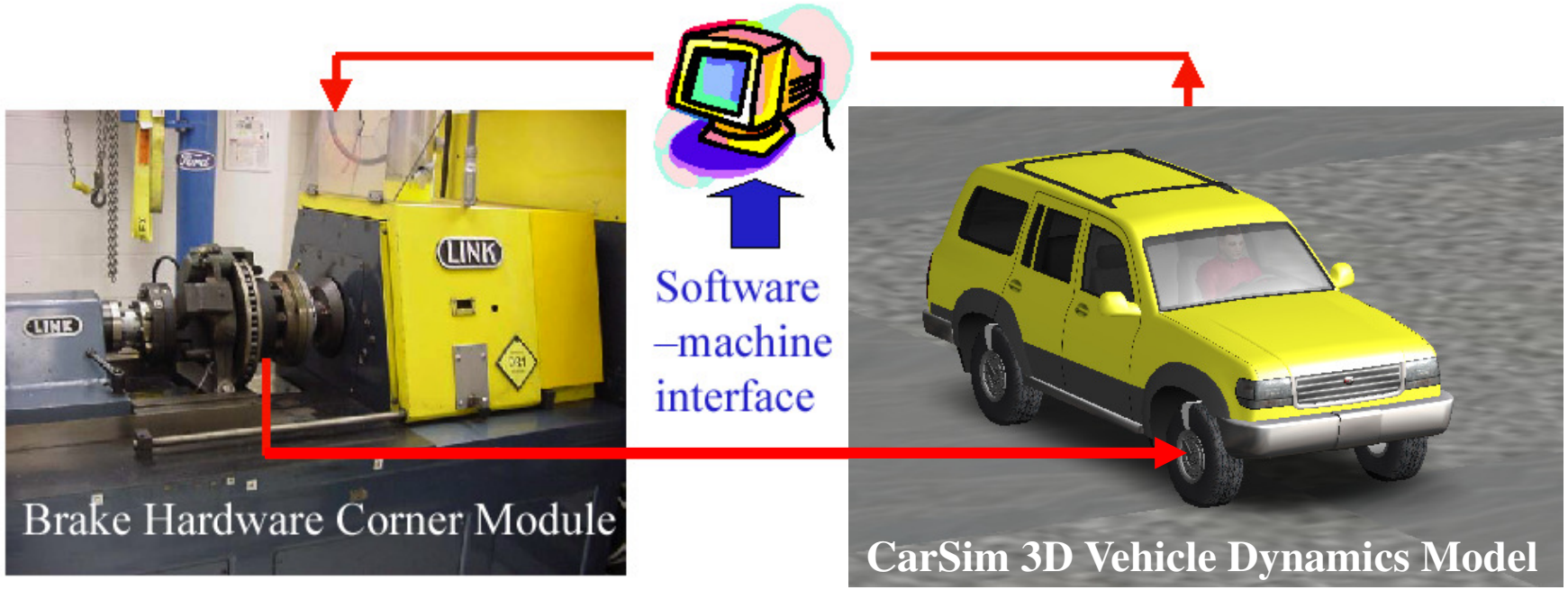
Mechanical Simulation



Advantages of HIL Testing

- Validate hardware for design intent at prototype or production stages
- Test controllers long before vehicle hardware is available
- Simulation facilitates testing with:
  - All environmental conditions (simulated roads and friction conditions)
  - Hardware stress conditions (temperature, voltage, vibrations, EMI)
  - Test safely in dangerous maneuvers (rollovers)
  - Safely test malfunctions and failures (shorts, open circuits, etc.)
  - Perfect repeatability
- Investigation of cause-effect relationships
- Track variables that cannot be measured
- Incorporate behavior of components that are difficult to model (e.g., brake lining temperature sensitivity)

HIL Example – Ford Brake System Development

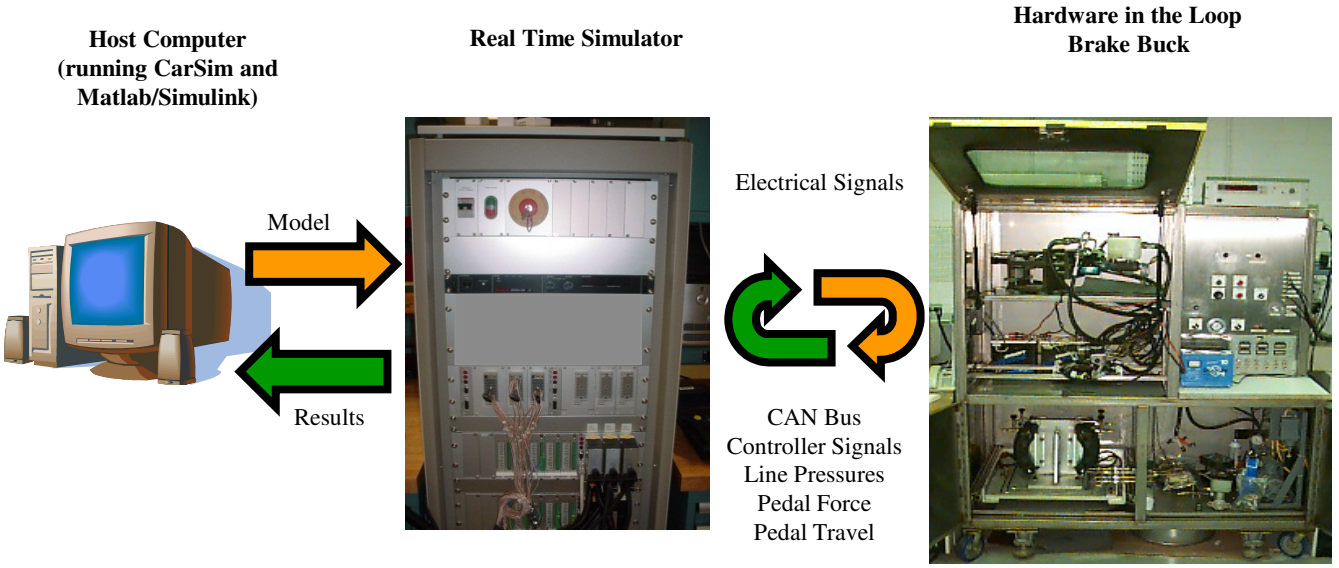


- Brake pad friction is hard to model
- Brakes were put on dynamometer
- CarSim supplied:
  - Car model
  - Maneuver control
  - Test site(s)
- Brake lining materials were certified!

Wei-Yi Loh, Ford Motor Company,
"Hardware in the Loop Simulation, Chassis Systems Applications"

HIL Example – GM Chassis Controls

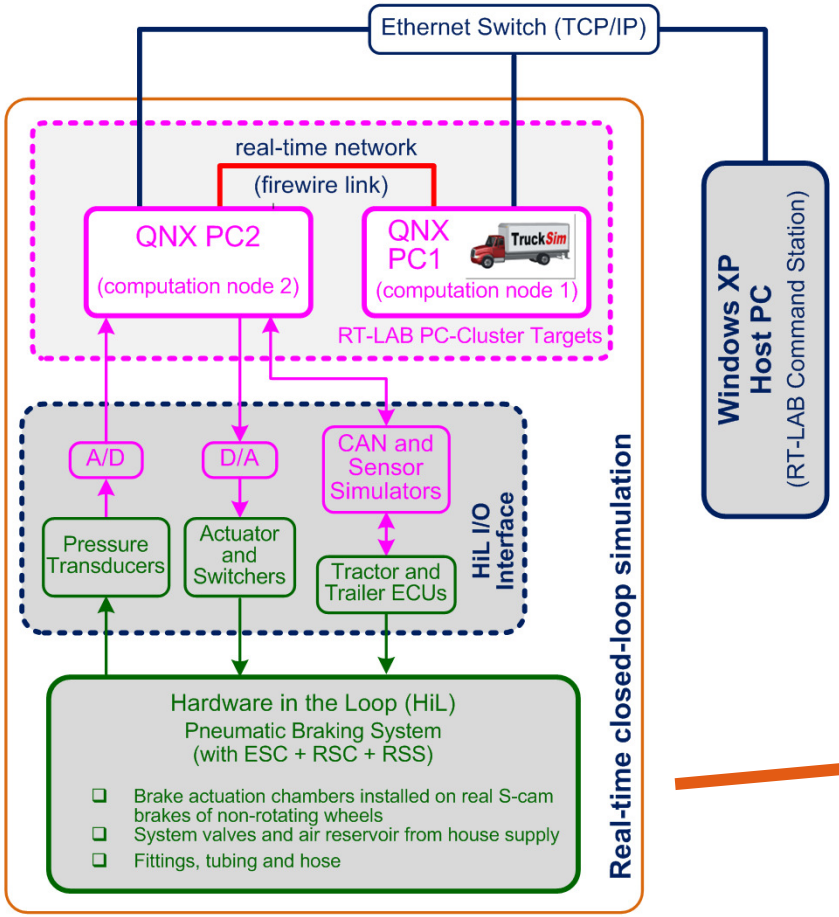
- "The fundamental idea behind HIL is to use simulation for the vehicle systems that can be modeled with high confidence and actual vehicle hardware for the systems that are difficult to model in real-time software."



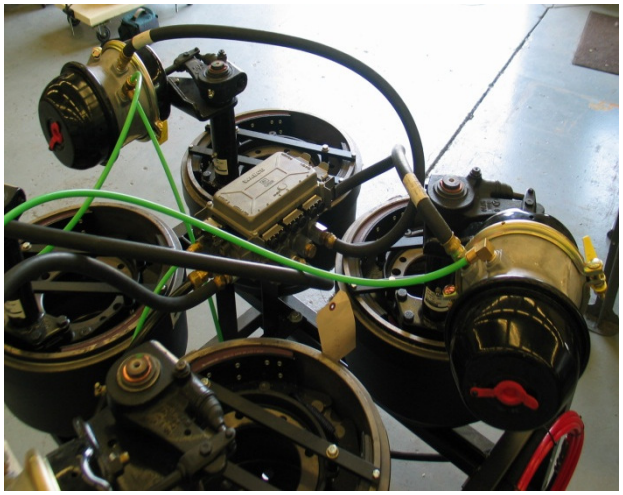
Cedric Mousseau, GM, "Chassis Control Simulation Development Processes at General Motors" Automotive Testing Technology International, 2008

HIL Example – Truck ESC Evaluation

- Goal – evaluate performance of truck ABS, ESC, RSC, RSS combinations
- Solution – set up a HIL laboratory with TruckSim



- Truck brake system hardware is installed in the laboratory
- Simulation evaluates performance over a broad range of real-world conditions



Tim Gordon, UMTRI, "HIL Tests for Truck ESC" Vehicle Dynamics International, 2008

Ref: Vehicle Dynamics International, May 2008

HIL Example – Driving Simulators

Traditional Applications

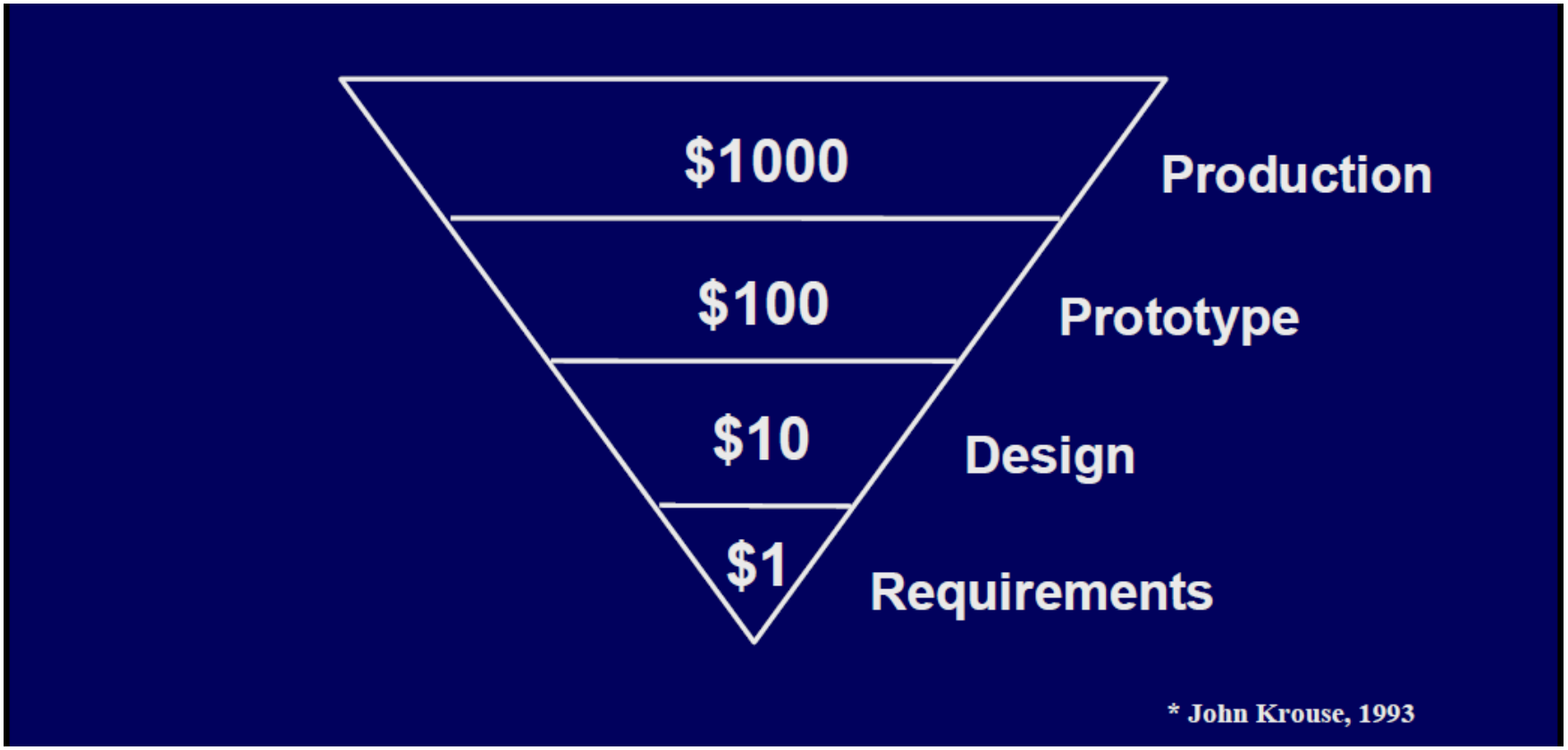
- Human factors testing
- Influence of drugs on driving
- Driver training
- Entertainment

Engineering Applications

- A/B testing of vehicle components
- Full-emersion systems tests
- Development & test engineer training
- Pre-construction road design evaluation

Simulation Improves Performance Prediction

- Cost of change increases throughout the development process
- Design refinement early in the process saves money



Steve M. Rhode, "Developing and Validating Products in a Virtual World"
Auto 599, Integrated Vehicle Systems Design, University of Michigan, 2005

Benefits of Math-Based Technology

- 50% productivity improvement in last several years
- Over 10^9 savings
- VDP time reductions >18 months

- CAE today is 7-10 times faster than hardware verification
- CAE costs are a fraction of test verification costs
- CAE will become the principle design verification & direction methodology!

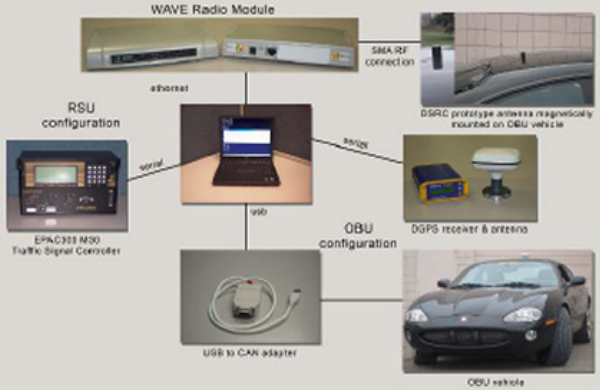
Steve M. Rhode, "Developing and Validating Products in a Virtual World"
Auto 599, Integrated Vehicle Systems Design, University of Michigan, 2005

CAMP – crash avoidance metrics partnership

VSC I
2002 - 2004

CAMP
Vehicle Safety Communications Consortium
DaimlerChrysler Research, Engineering and Design North America Inc. · GM · Toyota · Nissan · VW · Ford · BMW
IVI Light Vehicle Enabling Research Program

DSRC/WAVE Testing System



Potential Safety Applications

Vehicles - Vehicle

- Approaching Emergency Vehicle Warning
- Blind Spot Warning
- Cooperative Adaptive Cruise Control
- Cooperative Collision Warning
- **Cooperative Forward Collision Warning**
- Cooperative Vehicle Highway Automation System
- **Emergency Electronic Brake Lights**
- Highway Merge Assistant
- Highway/Rail Collision Warning
- **Lane Change Warning**
- Post-Crash Warning
- **Pre-Crash Sensing**
- Vehicle-Based Road Condition Warning
- Vehicle-to-Vehicle Road Feature Notification
- Visibility Enhancer
- Wrong Way Driver Warning

Vehicle - Infrastructure

- Blind Merge Warning
- **Curve Speed Warning - Rollover Warning**
- Emergency Vehicle Signal Preemption
- Highway/Rail Collision Warning
- Intersection Collision Warning
- In Vehicle Amber Alert
- In-Vehicle Signage
- Just-In-Time Repair Notification
- **Left Turn Assistant**
- Low Bridge Warning
- Low Parking Structure Warning
- Pedestrian Crossing Information at Intersection
- Road Condition Warning
- Safety Recall Notice
- SOS Services
- **Stop Sign Movement Assistance**
- Stop Sign Violation Warning
- **Traffic Signal Violation Warning**
- Work Zone Warning

Draft SAE Message Set

- **Longitude**
- **Latitude**
- **Height**
- **Time**
- **Heading Angle**
- **Speed**
- **Lateral Acceleration**
- **Longitudinal Acceleration**
- **Yaw Rate**
- **Throttle Position**
- **Brake Applied Status**
- **Brake Applied Pressure**
- **Steering Wheel Angle**
- **Headlight Status**
- **Turn Signal Status**
- **Traction Control State**
- **Anti-Lock Brake State**
- **Vehicle Length**
- **Vehicle Width**

Real World V-V Communication Performance

Publications at: http://www-nrd.nhtsa.dot.gov/pdf/nrd-12/060419-0843/

VSC Message Composition

- One common message supports all safety applications.
- Exchange with neighboring vehicles.
- Send periodically (heartbeat) or event-triggered.

SAE J2735 Basic Safety Message (BSM)	
Part I	**Basic Vehicle State Message Part I** (Veh. ID, Seq. #, time, position, motion, control, veh. size) *Part I is mandatory in BSM*
Part II	**Vehicle Event Object** (hard braking, control loss, etc.)
	Vehicle Path History Object
	Vehicle Path Prediction Object
	Relative Positioning RTCM 1002 data

Summary

- Vehicle complexity requires new methods for product development
- Virtual testing in the simulation world serves that purpose
  - Stage 1: Stand Alone
  - Stage 2: Software-in-the-Loop
  - Stage 3: Hardware-in-the-Loop
- These methods are used broadly in industry
- New applications are being conceived every day
  - Diverse applications in driving simulators
  - Evaluating road designs prior to construction
  - Developing experimental test procedures and protocols
- The bottom line
  - Cost savings in the millions
  - Time savings of months to years
  - The only viable solution in many cases

Thank You!

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