Taking advantage of plant modelling in the software development process

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Pi Innovo

Vehicle electronics innovators

The Problem

- Significant improvements in the quality and availability modeling and simulation resources, but are infrequently utilized by software developers
- Modeling and simulation is viewed as separate activities to the controls development process
- Software development lifecycles are long. Fixing design errors based on field failure data is prohibitively expensive
- Vehicle testing is difficult to schedule and is also very expensive

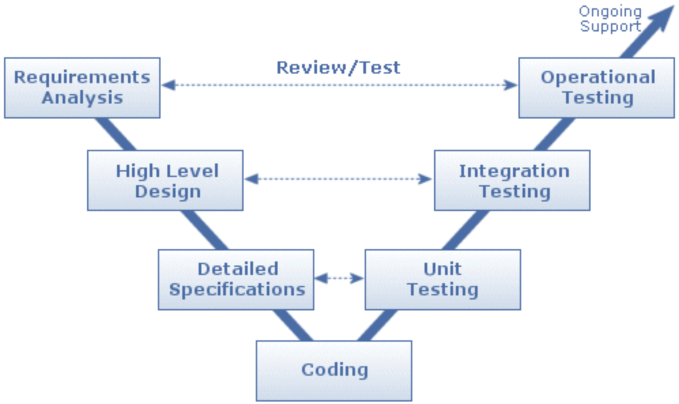
Constraints

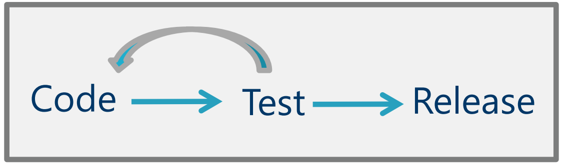
- To further constrain the broader adoption
  - Organizational structure
  - Internal & External budgets
  - Software development lifecycle model
  - Knowledge base for physics based modeling
  - Tools and co-simulation platform availability
  - Finding the right level of fidelity in the model
  - Calibrating and correlating the model

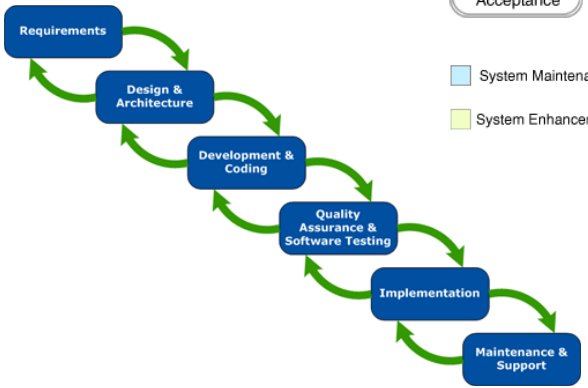
Realities

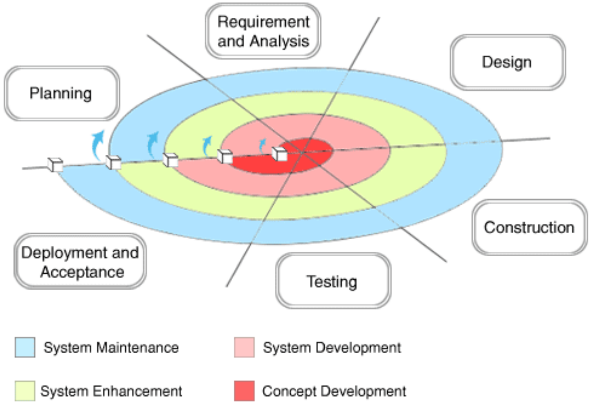
- Trust issues. Is the plant correct? Is it well correlated?
- Separate controls and simulation groups. No data sharing. Engineering silos
- People model a system larger than needed at too high of a fidelity
- The simulations take too long to run and the controls engineers can't be bothered to wait minutes for a single run to complete.
- Some evidence of using simulation, but it isn't fully integrated into the controls development process.

Common Software Development Lifecycles







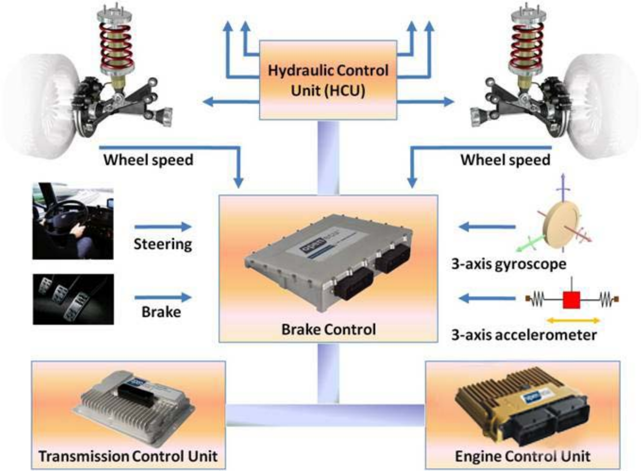


Case Study Details

- For the purpose of the discussion here all projects were conducted under a CMMI Level3 compliant development process.
- The software development lifecycles were tailored to support modeling and simulation during the software design, implementation, and software testing stages.
- Project subject matter in case studies varied from an active suspension system, vehicle rollover warning system, and a ABS/TCS/ESC system
- Each project used varying levels of fidelity in their plant models.

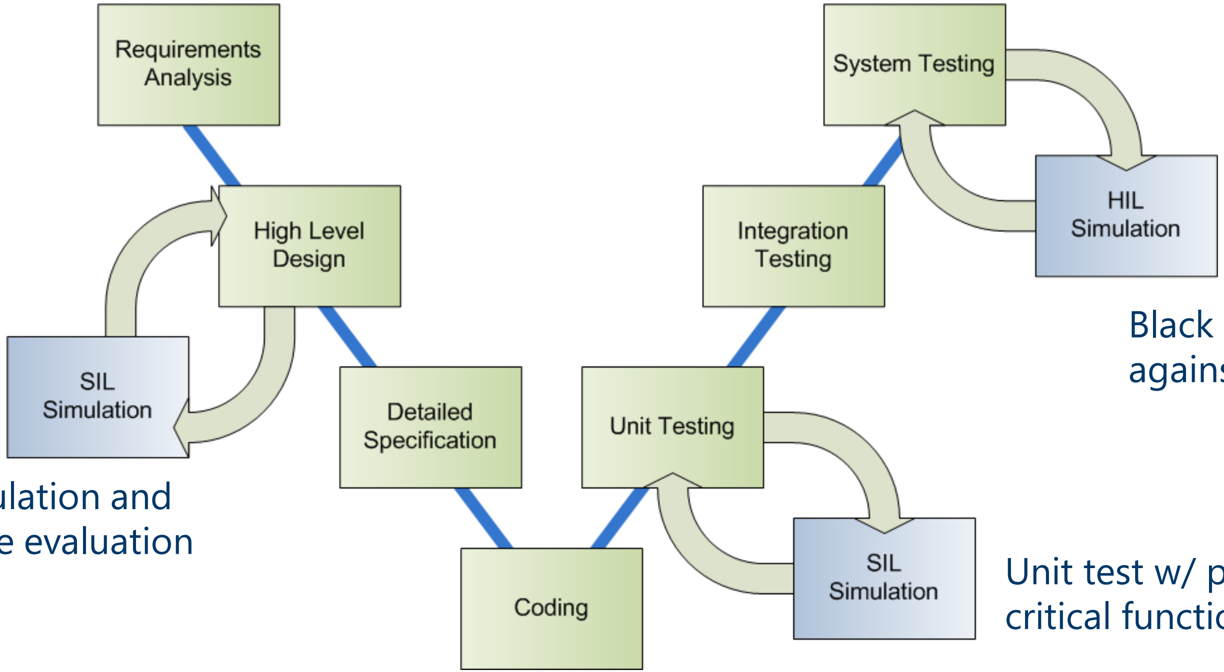
Case One – ABS/TCS/ESC System

- Customer contracted Pi Innovo to develop the controls for a combined ABS, Traction Control (TCS), and Electronic Stability Control (ESC) system.
- Minimal existing intellectual property was re-used. Clean sheet design.



Modified V-Model

Release to vehicle test



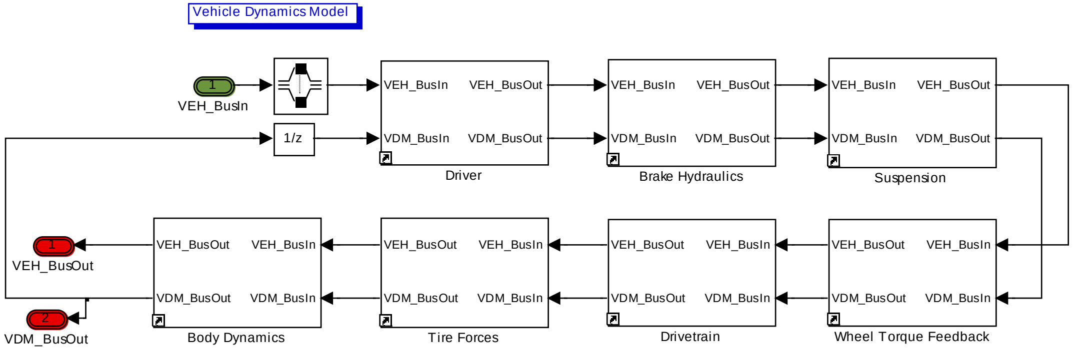
Black box testing against use cases

Unit test w/ plant for critical functions

Ad hoc simulation and performance evaluation

Case One – Test Configuration SIL

- Software-in-the-loop (SIL) testing conducted during design phase to support robust requirements definition of the software features.
- Re-utilized SIL testing during change management.
- Closed loop simulation in PC environment. Quasi real-time.
- Identical plant model to HIL simulation

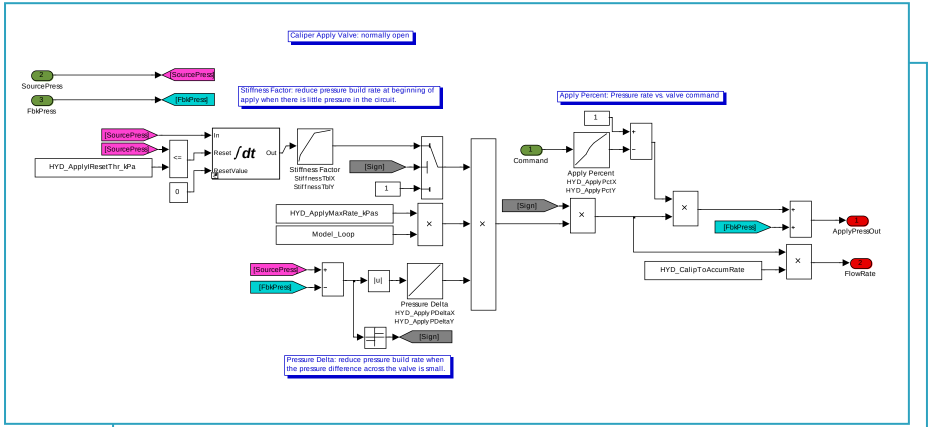


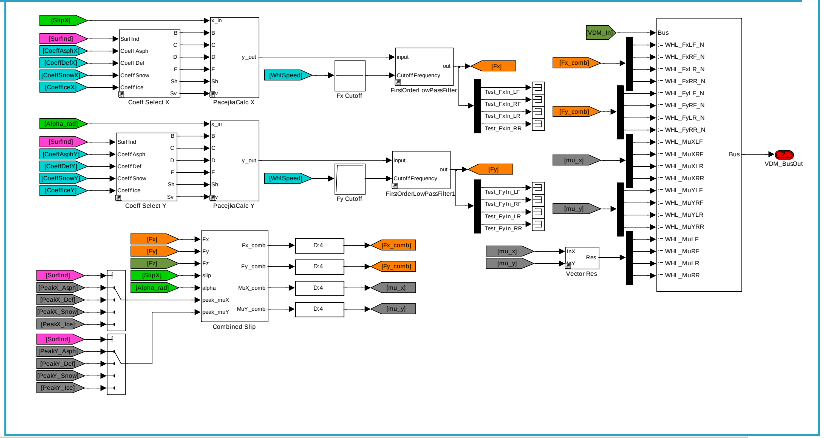
Case One – Test Configuration HIL

- Autosim Hardware-in-the-Loop (HIL) system.
- Physics based plant model (Simulink) running on HIL
- Control logic running on target ECU
- Closed loop, real-time simulation
- Option: add actual brake hydraulic components in the loop

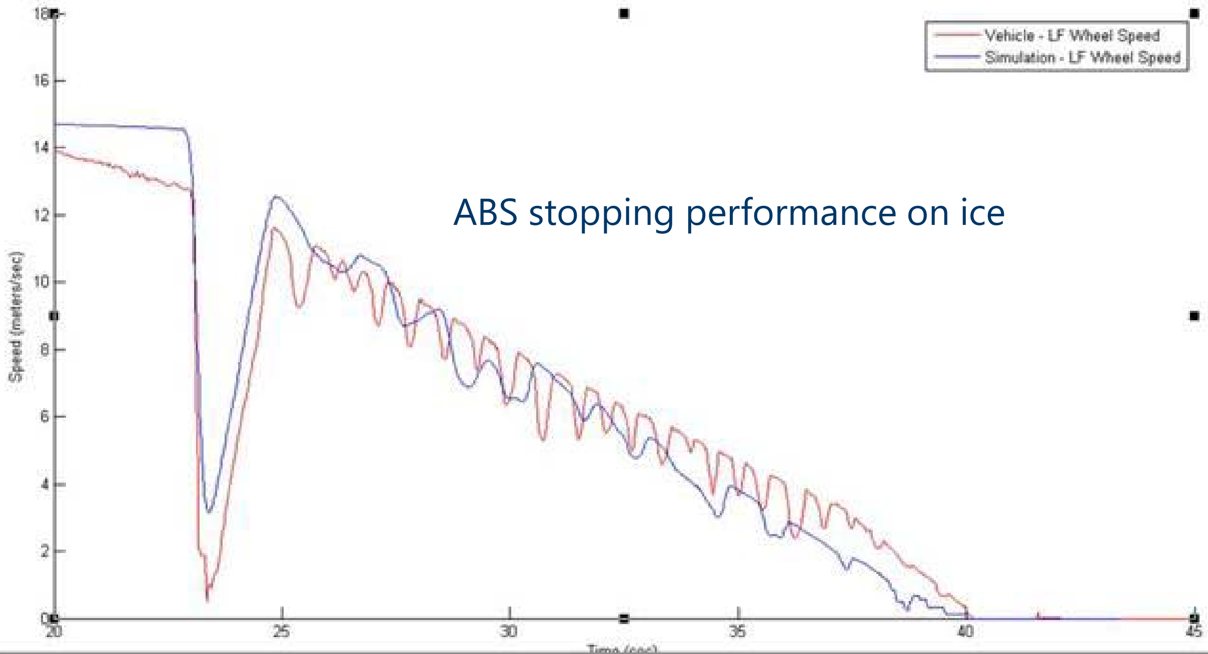
Case One – Plant Model

- Considerations
  - Driver steering effects
  - Brake hydraulics:
    - pump flow, valve flow, tank flow
    - accumulator pressure
    - brake caliper volume, stiffness, valve dynamics
  - Suspension dynamics: weight transfer due to pitch and roll
  - Drivetrain efficiency, inertia, and load
  - Pacejka Tire model
  - Vehicle Dynamics: Yaw, slip angles, roll, pitch
  - Pseudo random sensor noise





Simulation Output Results



ABS stopping performance on ice

Case One – Plant Model

- Certain dynamics were not considered
  - Fidelity requirements were geared to support basic controls software development
- Specific exclusions were:
  - Temperature & wear effects
  - Component variation
  - Caliper and valve friction
  - Brake pad friction vs. time vs. temperature
  - Internal leakage of hydraulics
  - Rough road models
  - Suspension stiffness & damping modeled with simple gains and low pass filters to provide overall bulk response to pitch and roll.

Case One – Medium Fidelity Plant Model

Pro

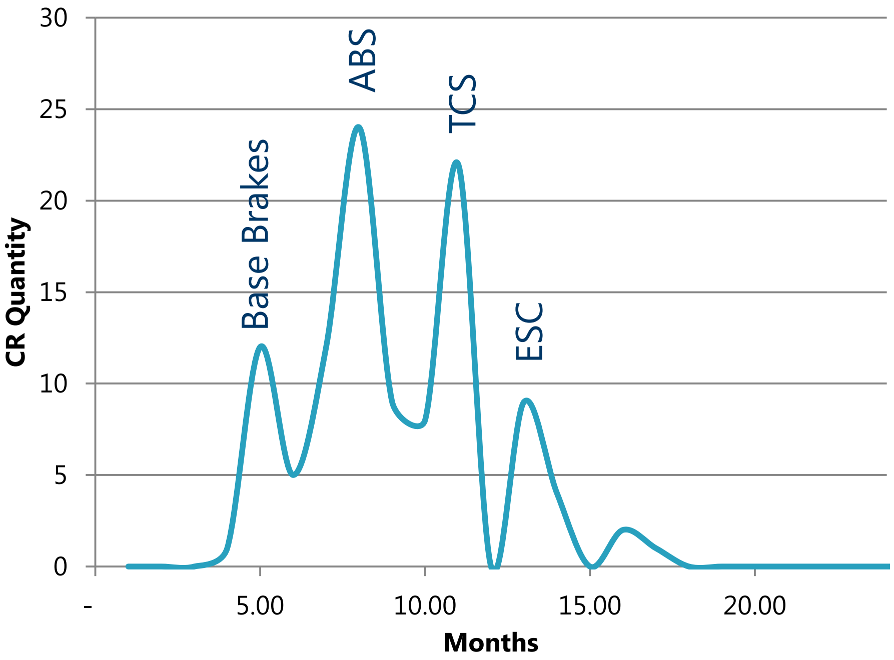
- Validate earlier in the development process
- Many control options evaluated in a short period of time
- Fits the traditional work habits of most software developers. Code first, ask questions (and provide documentation) later
- Baseline calibration more representative
- Eliminates the obvious design blunders
- Reduces the occurrence of controls design changes coming from field testing

Con

- Debugging often involves plant and control.
- Correlation to real world difficult to do if you are modeling a new system
- More time spent analyzing data over low fidelity output
- Requires more computational power to ensure plant runs at correct rate compared to controls
- Must augment SW development lifecycle to properly account for simulation

Case One – Project Metrics

- 1.5 years duration
- 25,000 man-hours
  - includes controls development and extensive vehicle testing
- 109 total Change Requests
- 144,000 total lines, 70,000 LOC
- Unit test in 10-60 min
- Black Box regression testing runtime of 3hrs
- First time pass of FMVSS126 test

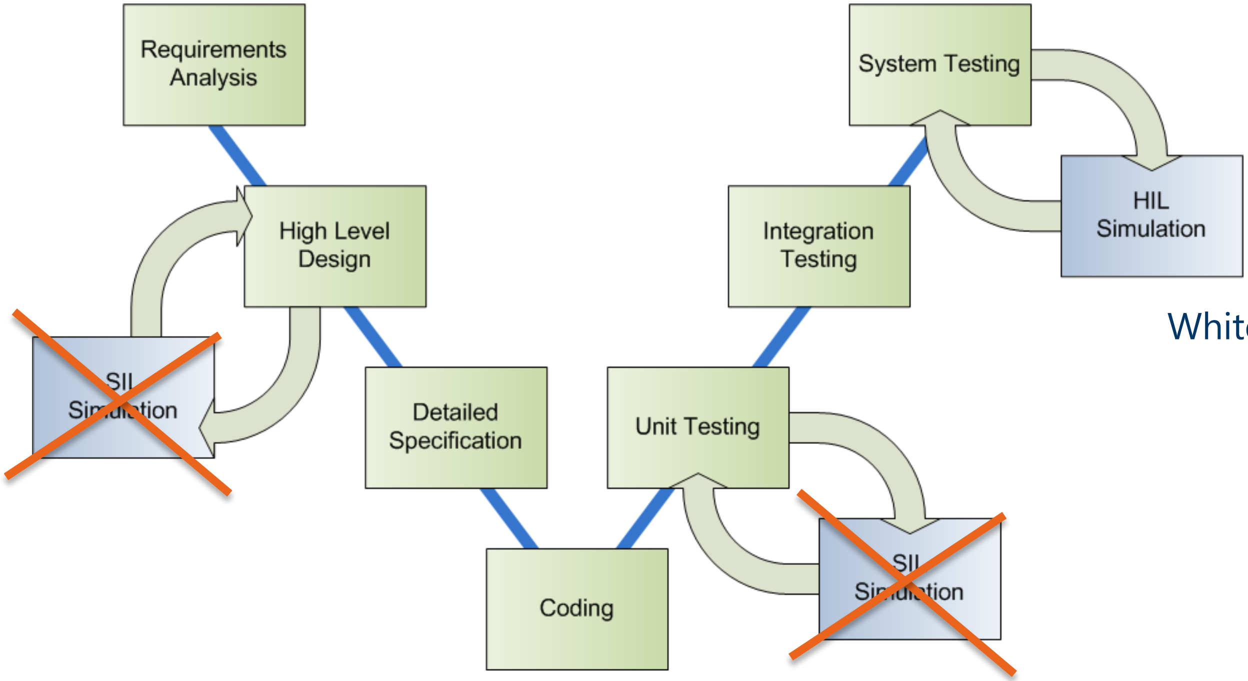


Case Two – Active Suspension System

- Customer contracted Pi Innovo to develop a control system for a novel active suspension system.
- Similar in scope and size to Case One.
- Clean sheet design. No prior intellectual property.
- New suspension technology for active components, minimal prior published work on the subject.

Case Two - Modified V-Model

Release to vehicle test



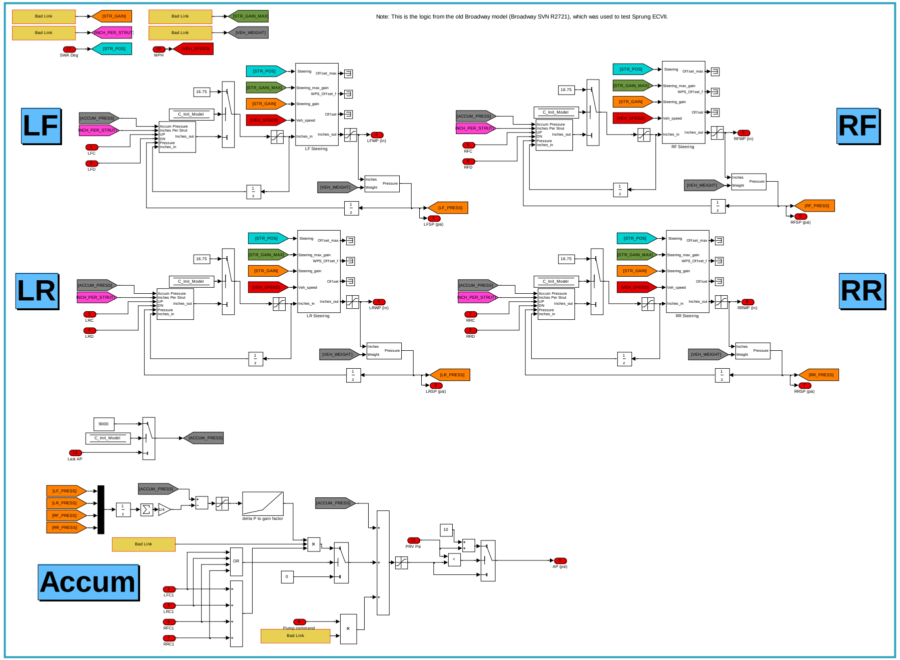
White Box Testing

Case Two – Test Configuration HIL

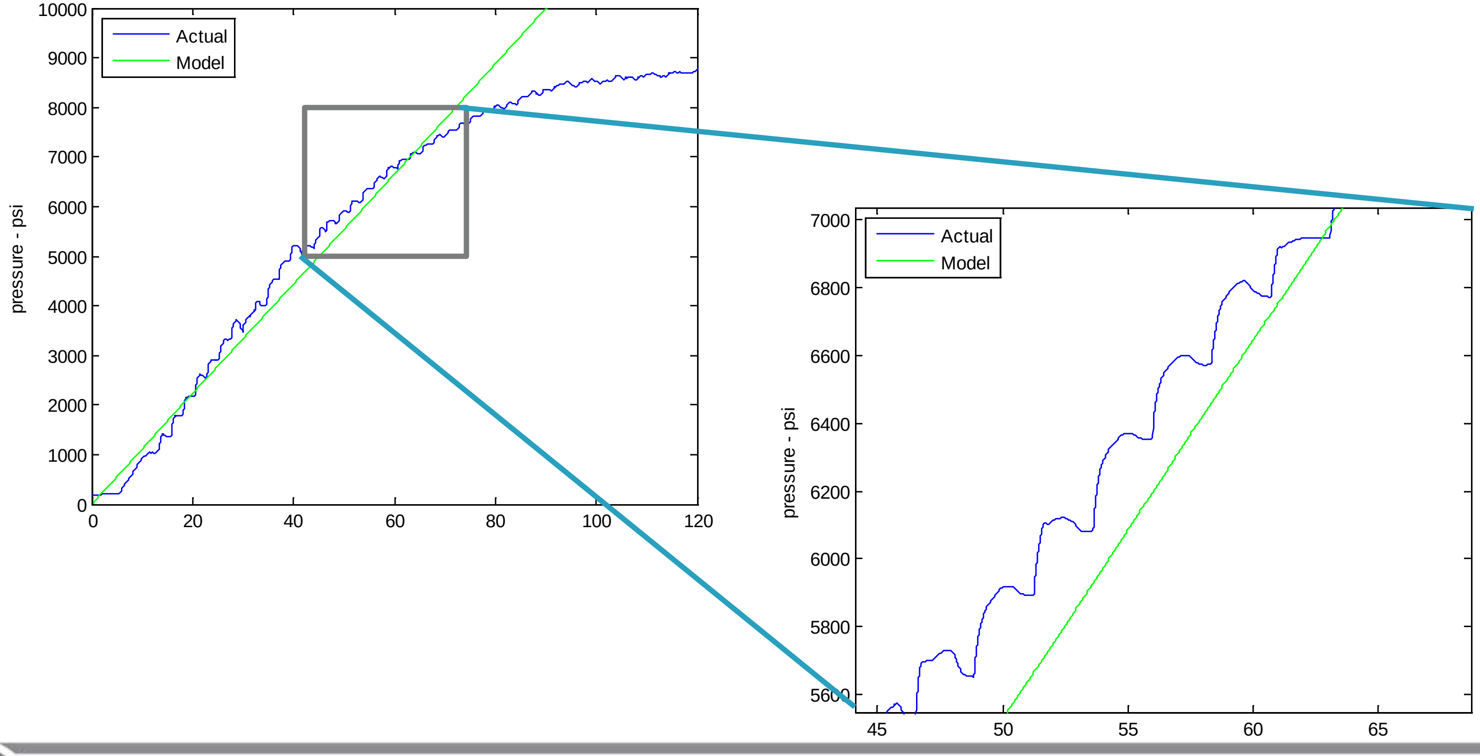
- Autosim Hardware-in-the-Loop (HIL) system.
- Low fidelity non-physics based plant model (Simulink) running on HIL
- Control logic running on target ECU
- Closed loop real-time simulation

Case Two – Plant Model

- No vehicle dynamics
- Hydraulics & vehicle statics focus. Non-physics based.
- *'for every millisecond the valve is open, increment pressure by 'x' kPa'*
- *'for every millisecond the valve is open, increment ride height by 'y' mm'*



Simulation Output Results



Case Two – Low Fidelity Plant Model

Pro

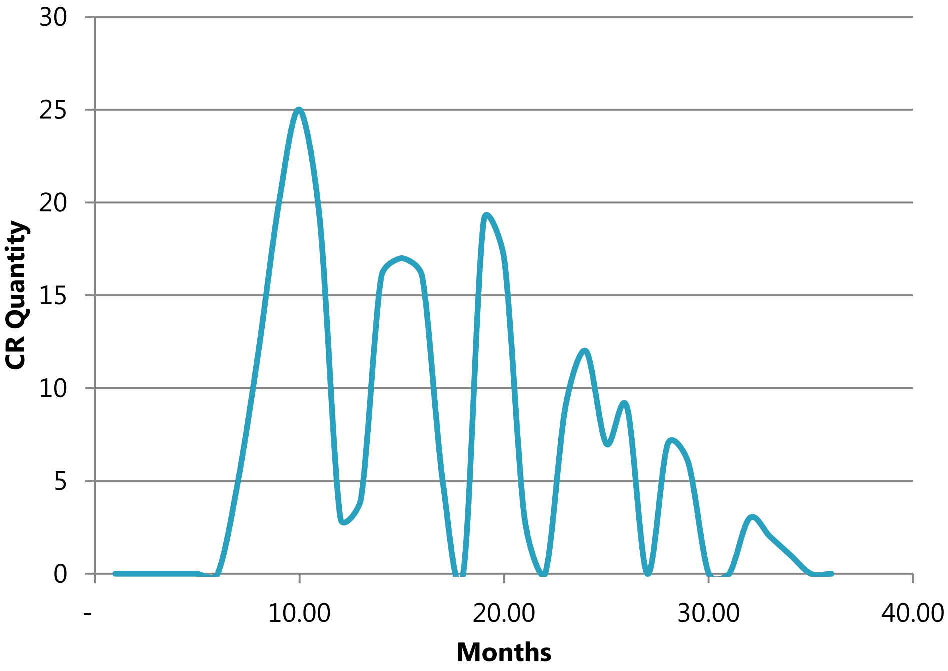
- Effort to develop is low
- Effort to validate/correlate is low
- Computationally simple / low overhead
- Evaluate bulk response of controls

Con

- Does not fully validate the design
- Does not provide a baseline calibration
- Effort to test with low fidelity model same as medium fidelity
- Costly. Can not validate design until post-release vehicle testing.

Case Two – Project Metrics

- 3 years duration
- 30,000 man-hours
  - includes controls development extensive vehicle testing
- 237 Change Requests
- 92,000 total lines, 46,000 LOC
- White Box regression testing runtime of 15hrs



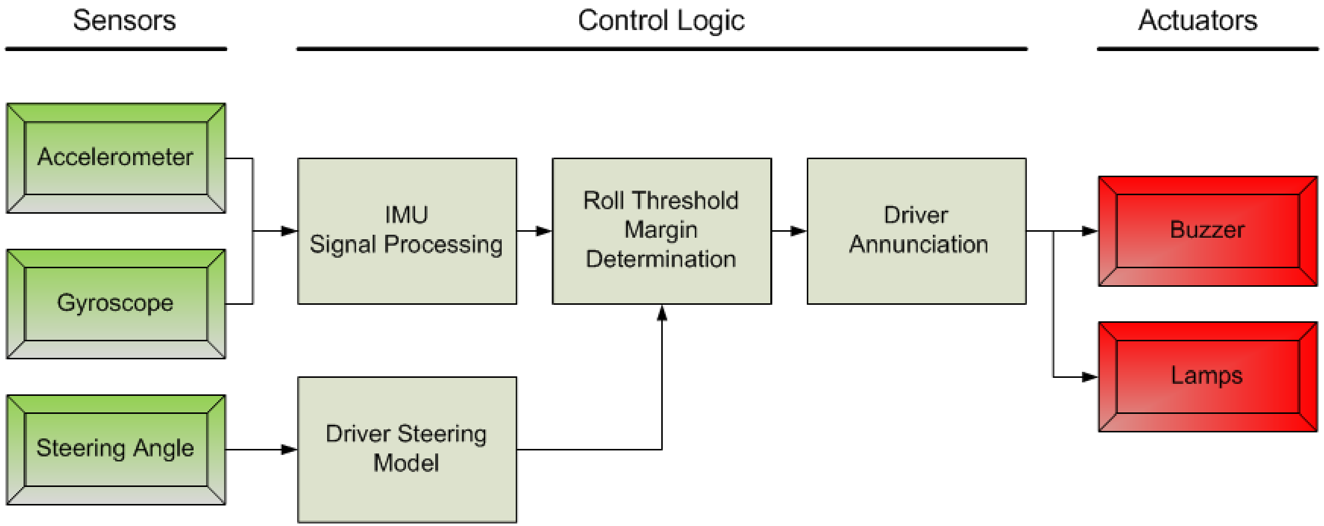
Case Three – Rollover Warning System

- No HIL test environment
- No SIL test environment
- Vehicle testing only

- Proof of concept prototype / technology demonstrator
- Show the effectiveness of warning drivers about impending rollover. Using accelerometer and gyroscope data, combined with a predictive element based on driver steering input as rollover prediction was made and annunciated to the driver.

Case Three – Rollover Warning System

- Driver steering and vehicle attitude model
- Simple threshold triggering for annunciation



Case Three - No Plant Model

- Suitable for feasibility studies or proof of concept projects
- Not recommended for safety critical systems of any kind
- No means to evaluate the design prior to release to vehicle test
- No ability to pre-calibrate the controls prior to release
- Only suitable if the actual test property is available to the software developers
- Only suitable to programs with ample time and budget

Case Three – Software Revision Metrics

- There are no software metrics
- Work commenced on Nov 4th with only high level user needs statement
- Functional prototype delivered Nov 17th

- 43 software versions over 13 days
- Desktop and vehicle testing only

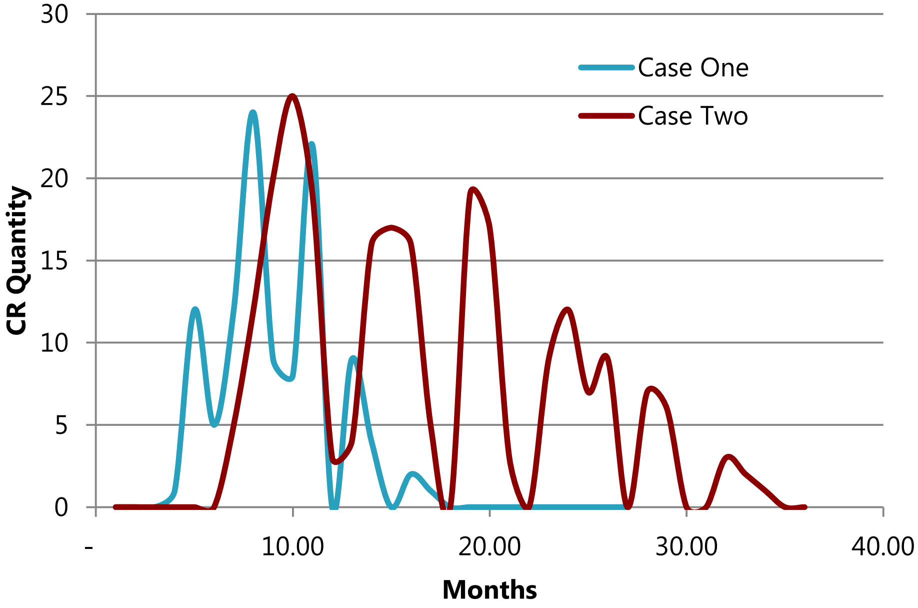
- Successful customer demonstration Nov 18th in vehicle.

Summary Questions

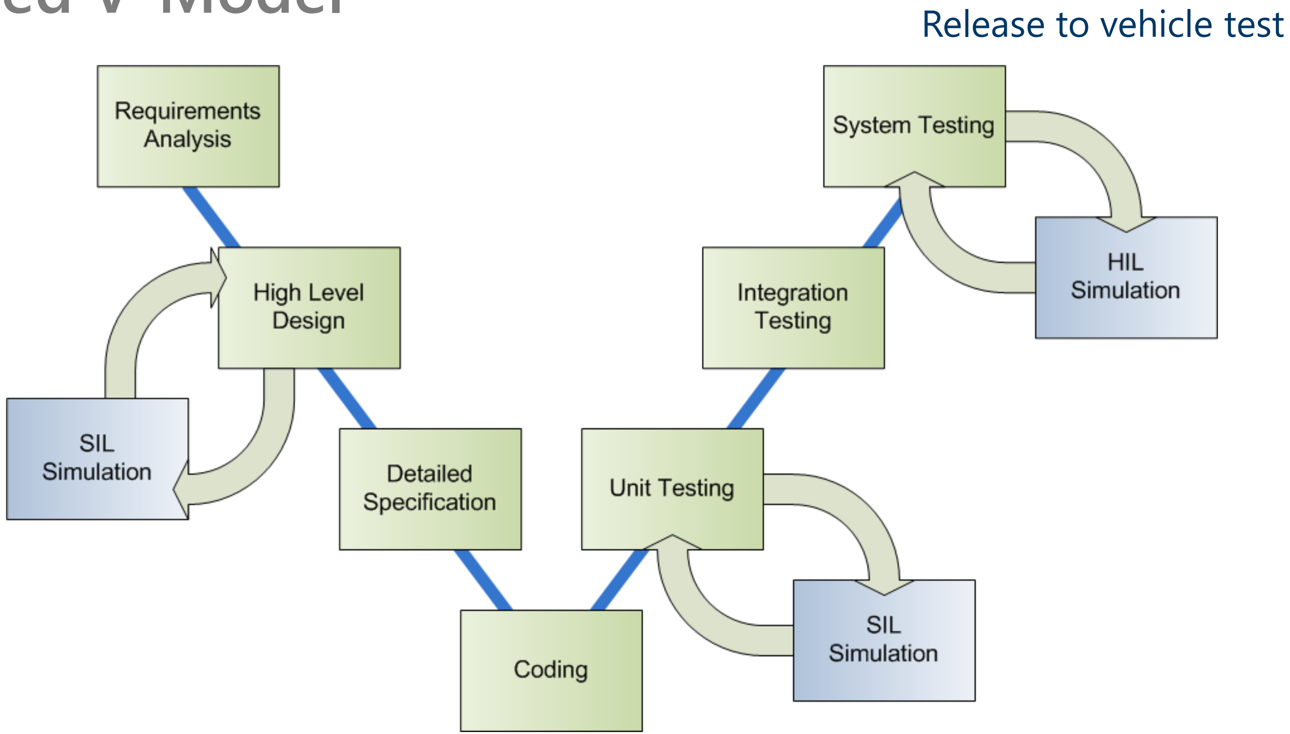
- Why was success variable between these examples?
- Was simulation the only differentiating factor in these examples?
- Is there a place for low fidelity non-physics based plant models?
- When should you choose to use physics based models in software development?
- What were the experiences of the project engineers and their thoughts?

Summary

- Case one was more efficient and effective than Case two
- Longer cycles between design validation (in-vehicle testing)
- 2x number of CRs
- 2x duration



Modified V-Model



Summary

- Case one was able to achieve high first time quality and pass federal compliance tests on the first try
- Case two project duration (and cost) was negatively impacted by not being able to validate the design choices early in development
- Case two costs were ~25% greater than Case one
- Case two duration was 2x longer than Case one
- Low fidelity, non-physics based models increase costs over medium fidelity physics based model when used in software development **
- Not every controls project needs a plant model – check your goals

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Thank you for your attention.

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