Establishing Model Based System Engineering as a Core Electric Vehicle Design Process

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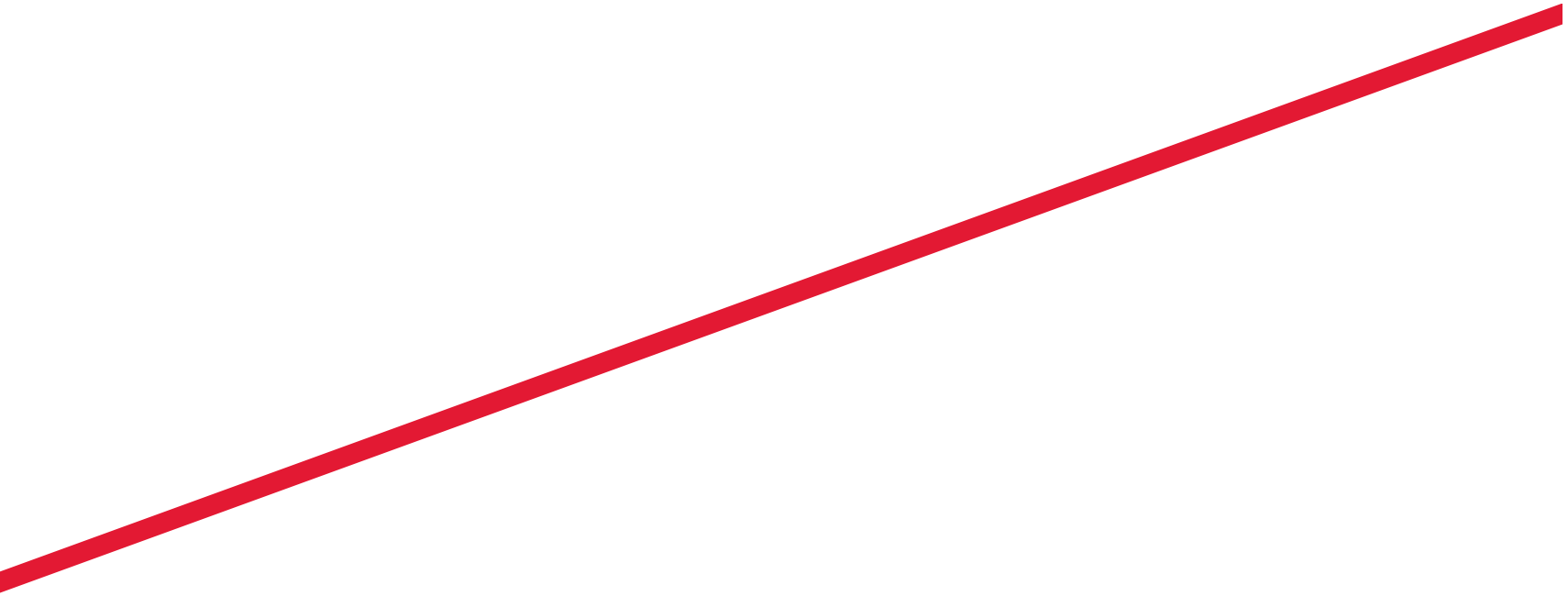

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System Engineering Fundamentals

- Deliverables of System Engineering
  - System Performance Specifications
  - System Architecture
  - Function List
  - Subsystem Interface Specifications
  - Analysis and Trade-off
  - Test Cases

Model Based System Engineering

- Advantages
  - Visual representation of requirements
  - Easier to be reviewed by a large team
  - Fairly independent of linguistic nuances
  - More complete representation than what can be explained in a text document
  - Facilitates code automation and test automation

Four Pillars of System Engineering

Structure

- Internal Block Diagram
- Subsystem interfaces
- Calibration Parameters

Behaviour

- Allocation of Functions
- Desired Functions
- Fault handling and diagnostics
- User input
- Instrumentation

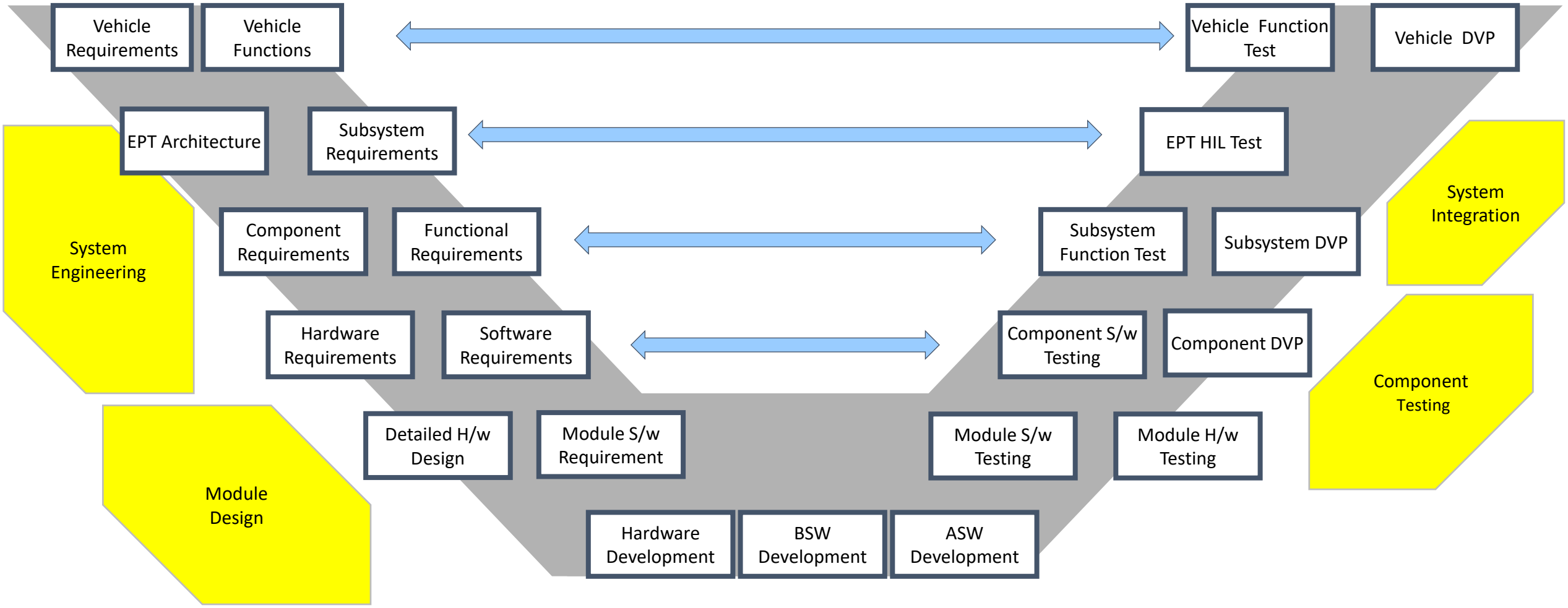
Requirements

- Function requirements
- Test cases to verify functions
- Definition of which subsystem is expected to satisfy each function

Parametrics

- Parametric behaviour of system - Plant Model
- Valid and plausible limits of system variables

System Engineering V-Cycle



System Interface Definitions

- Six dimensions of Interface Definition
  - Mechanical
  - Electrical
  - Signal
  - Control
  - Heat Transfer
  - Mass Transfer
- System Engineering Teams should necessarily have experts in all the above domains
- Every interface parameters should have nominal, minimum and maximum values
- Every system measurement should have valid minimum, valid maximum, plausible minimum, and plausible maximum limits.
- Every function definition should specify
  - What the function shall do
  - What the function should not do
  - How the function shall gracefully “fail” in the event of invalid or incoherent inputs

Requirements

- Every function requirement definition should specify
  - What the function shall do
  - What the function should not do
  - How the function shall gracefully “fail” in the event of invalid or incoherent inputs
- Every function requirement should also have test cases
  - Positive test cases to test how the intended outcomes are realised
  - Negative test cases to test that the unintended outcomes do not materialise
  - Diagnostics test cases to test if the failure of function is securely and reliably informed to the user or service technician

Behaviour

- Function Allocation
  - Detail out the system functions into subsystem functions
  - Reconcile the subsystem inputs and outputs with the subsystem functions
  - Create global variables shared across subsystems and define their owners
  - Define time sequence of signals which are involved in function execution

Parametrics

- Fidelity of Plant Model crucial for effective testing of functions
- Effective Plant Model should capture
  - Nominal function of the vehicle system
  - Behaviour of the vehicle system if the system inputs are out of range
  - Adequate dynamic behaviour of system to account for delays in system response
  - All interfaces with the controller with the appropriate scaling
- Parameters
  - All system parameters that have significant effect on system behaviour should be modelled
  - All calibration parameters that affects the response of the controller should be modelled

System Engineering Process

- Set up System Engineering Team
  - Distinct from Vehicle Integration teams
  - Multi-talented team comprising of electrical engineers, embedded engineers, mechanical engineers, etc.
  - Empowered to directly interact with product planning and field teams to translate implied and explicit customer requirements to function specifications
  - Responsible for creating Statement of Requirements for each subsystem with each requirement traceable to the overall vehicle requirement
  - Have the capability to mathematically model the vehicle systems and subsystems in the context of control functions
  - Authorized to undertake detailed design review of each aggregate and/or subsystem within the vehicle
  - Exclusive sanction to add, delete, or modify functions at the vehicle and subsystem level

System Engineering Workflow

- Create system engineering workflow based on the V-cycle
- Establish regular cadence for senior level review of function requirements, error states and diagnostics requirements
- Integrate System Engineering deliverables to project gateway deliverables
- Define function maturity levels and link them to vehicle DVP and component PPAP stages

Things to Watch out for in System Engineering Reviews

- Consistency of subsystem outputs feeding other subsystem inputs
- Complicated system state diagrams
- System startup and shutdown sequences – race conditions, undefined states, incomplete shutdowns
- Too sensitive fault responses causing frequent shutdowns
- System shutdown without de-rating
- No clear recovery mechanism once the fault condition vanishes
- Lack of redundancy for safety-critical measurements
- Scope Creep