SYSTEMS ENGINEERING - VEHICLE AS A SYSTEM

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INTRODUCTION

Systems Engineering is a holistic, interdisciplinary approach that integrates different subsystems into a single functional vehicle system. It ensures that vehicles meet performance, reliability, safety, and efficiency requirements while optimising cost and development time.

Why Systems Engineering in Vehicle Development?

- Improves efficiency and modular design.
- Enhances safety and compliance with industry standards.
- Reduces complexity by breaking down the vehicle into subsystems.
- Optimises integration of electric, electronic, and mechanical systems.
- Ensures alignment with customer needs, regulations, and emerging technologies.
- Facilitates seamless communication between different engineering domains.

VEHICLE AS A COMPLEX SYSTEM

A vehicle consists of multiple interdependent subsystems, each contributing to the overall performance and functionality of the vehicle.

Key Automotive Subsystems:

- **Powertrain System** – Includes Internal Combustion Engine (ICE) or Electric Drive (EV), transmission, and drivetrain.
- **Chassis System** – Handles structural integrity, suspension, and braking.
- **Electrical & Electronic Systems (E/E Systems)** – Covers battery management, ECU integration, ADAS, and in-vehicle networks.
- **Thermal Management System** – Ensures cooling and heating efficiency.
- **Vehicle Dynamics & Control Systems** – Includes steering, braking, and traction control.
- **Human-Machine Interface (HMI) & Infotainment** – Ensures user-friendly interaction and connectivity.
- **Safety & Regulatory Compliance** – Adheres to ISO 26262 (Functional Safety) and cybersecurity protocols.
- **Manufacturing & Supply Chain Management** – Ensures cost-effective production and material sourcing.

Example - System Engineering in EVs

- Battery Management System (BMS): Integrates power electronics, cooling systems, and real-time monitoring.
- Electric Powertrain Optimisation: Balances torque distribution, energy efficiency, and regenerative braking.
- Autonomous Driving Systems: Merges sensor fusion, AI decision-making, and vehicle control algorithms.

VEHICLE SYSTEM ARCHITECTURE & DESIGN METHODOLOGY

Vehicle System Design Process

1. **Concept Development** – Define vehicle objectives, key attributes, and customer expectations.
2. **System Decomposition** – Break the vehicle into functional modules.
3. **Requirement Definition** – Translate customer needs into technical specifications.
4. **System Integration & Testing** – Validate performance, safety, and efficiency.
5. **Verification & Validation (V&V)** – Ensure compliance with regulations and quality standards.
6. **Lifecycle Management** – Maintain and update the system throughout its operational life.

Types of System Architectures

- **Centralised Architecture** – A single control unit manages multiple subsystems.
- **Distributed Architecture** – Multiple ECUs communicate over CAN, LIN, Ethernet networks.
- **Domain-Based Architecture** – Clusters related functionalities into specific domains (e.g., powertrain, body control, ADAS).
- **Zonal Architecture** – Latest approach that reduces wiring complexity by grouping functions in localised zones.

Example - EV System Architecture Optimisation

- Modular battery pack design to support various vehicle models.
- Integrated thermal management to enhance battery longevity.
- Cloud-based software updates for remote diagnostics and feature enhancements.

MODEL - BASED SYSTEMS ENGINEERING (MBSE) IN AUTOMOTIVE DESIGN

Model-Based Systems Engineering (MBSE) replaces document-based engineering with digital models and simulations.

Why Use MBSE?

- Enables virtual prototyping before physical production.
- Improves communication across cross-functional teams.
- Reduces design errors and optimises early-stage development.
- Enhances predictive maintenance with AI-driven analytics.
- Supports traceability and regulatory compliance throughout the product lifecycle.

MBSE in EV Development:

- MATLAB/Simulink Models for energy consumption analysis.
- Digital Twin Technology for real-time performance monitoring.
- Failure Mode & Effects Analysis (FMEA) to enhance reliability.
- AI-based predictive analytics for battery life estimation.
- Hardware-in-the-Loop (HIL) Testing to validate electronic components.

VEHICLE SUBSYSTEMS & INTERCONNECTIVITY

Key Functional Domains:

- **Powertrain & Energy Management**
    - EV motor efficiency and regenerative braking.
    - Smart charging and battery optimisation.
    - Vehicle-to-Grid (V2G) connectivity.
- **Chassis & Dynamics Control**
    - Electronic Stability Program (ESP) & Traction Control.
    - Active suspension for optimised ride comfort.
    - Tire pressure monitoring system (TPMS).
- **Electrical & Electronic (E/E) Systems**
    - Vehicle communication networks (**CAN, LIN, Ethernet**).
    - Infotainment & connectivity (5G-enabled vehicle systems).
    - Cybersecurity protection for over-the-air (OTA) updates.

- **Thermal Management & HVAC**
    - Battery cooling and heating for optimised temperature control.
    - Heat pump integration for energy-efficient climate control.
    - Waste heat recovery to improve vehicle efficiency.
- **Manufacturing & Supply Chain Optimisation**
    - Sustainable material sourcing for EV production.
    - Advanced robotics & automation in vehicle assembly.

Example - System Interconnectivity in EVs

- Cloud-based AI systems monitor battery performance and adjust energy usage dynamically.
- Smart charging stations communicate with vehicles to optimise grid load.
- Autonomous driving systems leverage ADAS sensors for real-time road analysis.

FUTURE OF VEHICLE SYSTEMS ENGINEERING

Emerging Trends in Automotive Engineering

- Software-Defined Vehicles (SDVs) – EVs evolving into software-centric platforms.
- AI-Driven Predictive Maintenance – Advanced analytics for fault detection.
- Zonal Architectures – Simplified wiring, reduced latency, and modular scalability.
- Wireless Power Transfer (WPT) – Wireless EV charging advancements.
- Human-Centric Vehicle Design – Adaptive interfaces and personalised user experiences.

Example - Next-Gen EV Architecture

- **F**ully Autonomous Vehicle Systems (L4-L5) integrating AI decision-making.
- Battery-Swapping Technologies for reducing charging downtime.
- Blockchain-based cybersecurity for vehicle-to-cloud transactions.