Testing strategies in the automotive industry

Lecture 7

Schedule

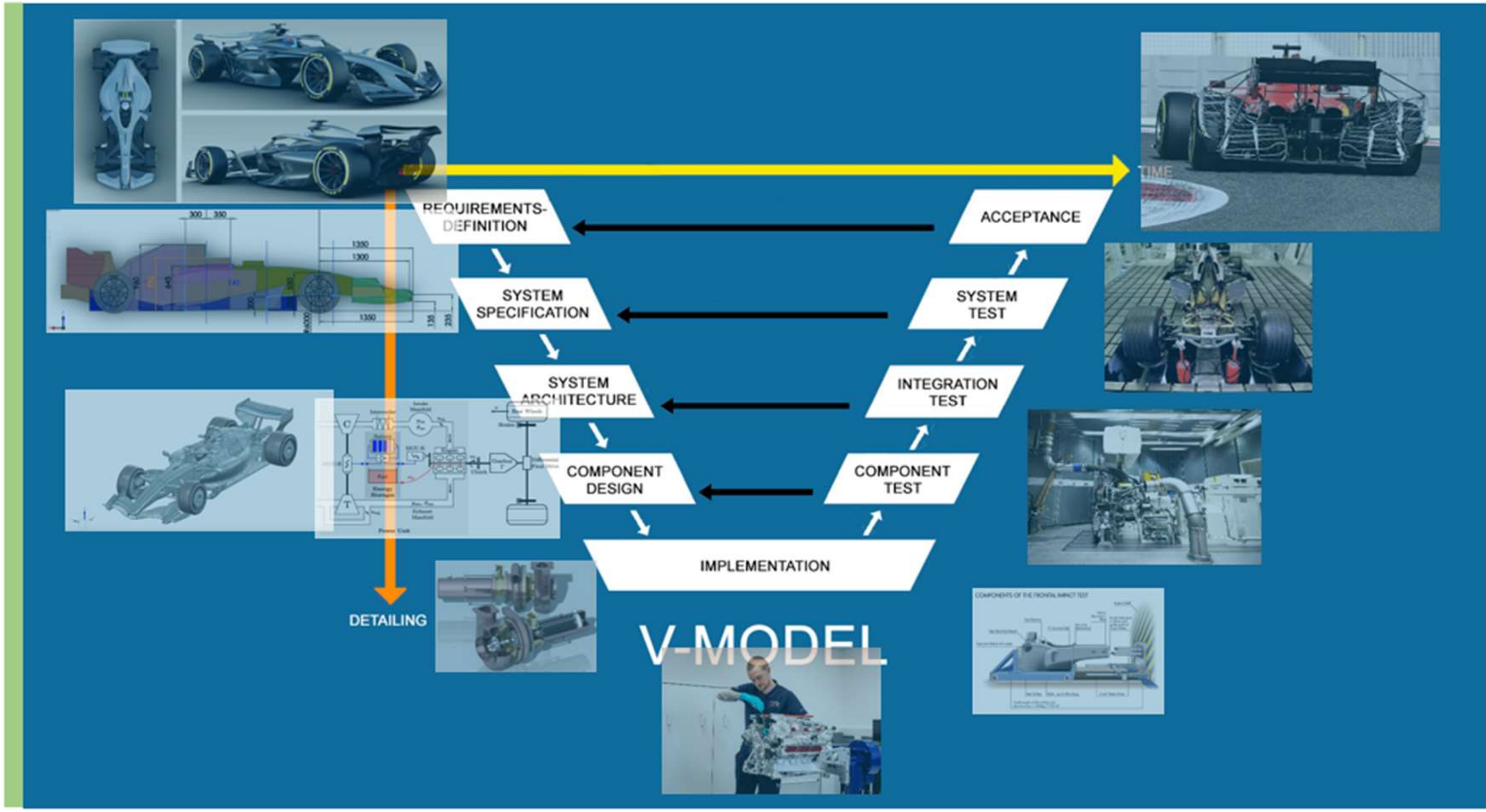
BME Automotive Technologies

Week nr.	Date	Lecture (Wednesday)			Lab (Wednesday)		Comment
1	09.04.	1	General information		1	Lab	
2	09.11.	2	Development methods		2	Lab	Online
3	09.18.	3	Design goals and requirements		3	Lab	
4	09.25.	4	Conceptualization I		4	Lab	
5	10.02.	5	Design guidelines		5	Lab	
6	10.09.	6	Testing strategies in the automotive industry		6	Lab	
7	10.16.	T1	Midterm exam I.				
8	10.23.	B	National holiday				
9	10.30.	7	System level testing		T1 R	Exam 1 - Retake	Online
10	11.06.	8	Performance and reliability testing		7	Lab	
11	11.13.	9	Troubleshooting and error calculation		8	Lab	
12	11.20.	10	Project management		9	Lab	Online
13	11.27.	T2	Midterm exam II.				
14	12.04.	T2R	Exam 2 - Retake				

- Introduction to automotive testing
- Types and examples of automotive testing
- Test frameworks
- Testing methodologies for system level testing
- Q & A

V-model status

- Reminder, where are we?



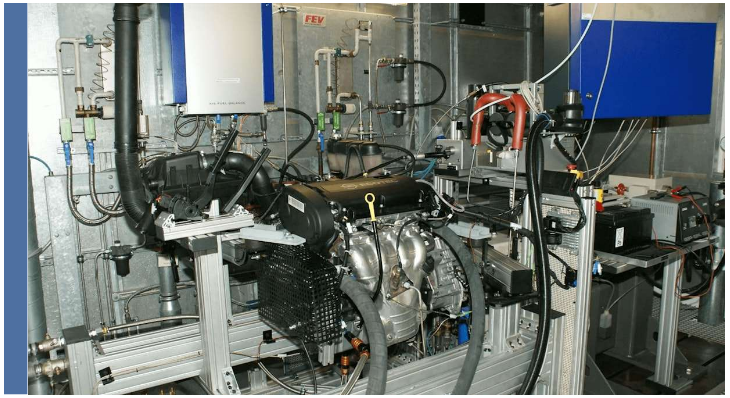
Introduction to automotive testing

BME Automotive Technologies

- Importance and overview
  - Testing ensures that vehicles are **safe** for both occupants and pedestrians. It identifies potential hazards in various scenarios like collisions, mechanical failures, or environmental conditions.
  - Vehicles must **meet legal and industry standards** (e.g., Euro NCAP, NHTSA, ISO standards) before they can be sold. Testing helps automakers prove their vehicles comply with these regulations, including emissions, safety, and performance.
  - Testing verifies that a vehicle or its components **meet the performance benchmarks set during the design phase**. This ensures that the car performs optimally under expected driving conditions.
  - Automotive testing evaluates how well the vehicle and its components withstand **long-term use** and adverse conditions, such as extreme temperatures, rough roads, or heavy loads.
  - **Early identification of potential design flaws** or material failures through testing helps manufacturers avoid costly recalls and warranty claims.
  - Testing ensures that vehicles **meet customer expectations** in terms of comfort, safety, and performance, which builds brand reputation and customer loyalty.
  - Testing facilitates innovation in automotive design and technology by verifying the functionality of new materials, components, or systems. It allows manufacturers to experiment and refine without compromising safety or performance.
- Key objectives: safety, compliance, performance, validation, reliability, detection, customer-satisfaction

Types and examples of automotive testing

- Component
  - Testing individual parts or subsystems before integration into the full vehicle.
  - Ensure each part meets quality, safety, and performance standards.
  - Examples:
    - Brakes: Test wear, heat resistance, and performance under different conditions.
    - Airbags: Verify proper deployment speed and efficiency.
- System
  - Testing the interaction of multiple components working together as a system.
  - Ensure proper functionality and safety of integrated systems.
  - Examples:
    - Powertrain: Evaluate engine and transmission performance.
    - Infotainment: Check connectivity, user interface, and system response.
- Vehicle
  - Testing the complete vehicle under real-world and simulated conditions.
  - Validate overall safety, durability, and performance.
  - Examples:
    - Crash Tests: Ensure passenger safety in collisions.
    - Durability Testing: Assess long-term wear and environmental resistance.



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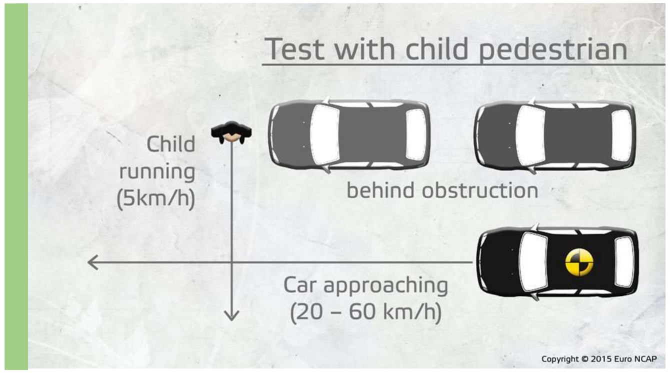
Types and examples of automotive testing

- Euro NCAP
  - Euro NCAP (European New Car Assessment Programme) is an independent organization that provides safety ratings for new cars sold in Europe. Established in 1997, Euro NCAP conducts a series of rigorous crash tests and evaluations to assess the safety of vehicles, including:
    - Crash Tests: Simulations of various types of collisions (frontal, side, rear) to see how well the vehicle protects its occupants.
    - Safety Assistance Technologies: Evaluation of systems like autonomous emergency braking (AEB), lane-keeping assistance, and driver monitoring.
    - Vulnerable Road Users: Assessment of pedestrian and cyclist protection in the event of an impact.
  - Cars are given a rating between **1 and 5 stars**, with **5 stars** representing the highest safety standards. These ratings help consumers make informed decisions about the safety of vehicles and encourage manufacturers to improve safety technologies.



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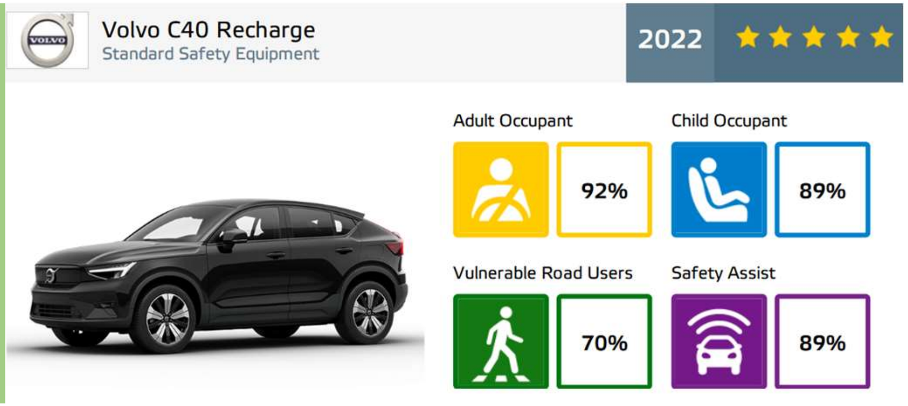
Types and examples of automotive testing

- What are the key objectives here?
  - safety, ~~compliance~~, ~~performance~~, validation, ~~reliability~~, detection, customer-satisfaction



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Types and examples of automotive testing

TEST RESULTS

EURO NCAP

SAFETY EQUIPMENT

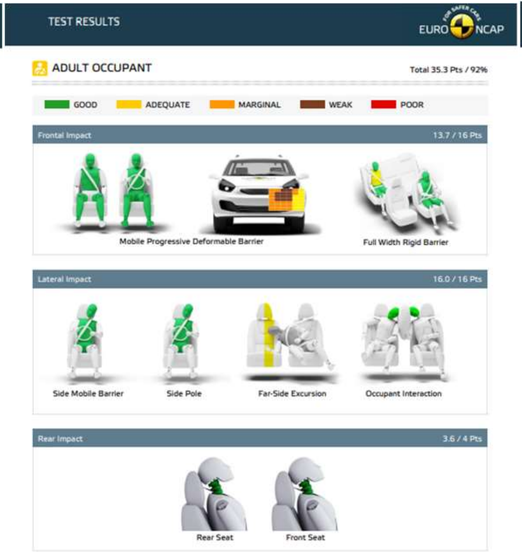
	Driver	Passenger	Rear
FRONTAL CRASH PROTECTION			
Frontal airbag	●	●	✖
Belt pretensioner	●	●	●
Belt loadlimiter	●	●	●
Knee airbag	●	✖	✖
SIDE CRASH PROTECTION			
Side head airbag	●	●	●
Side chest airbag	●	●	✖
Side pelvis airbag	●	●	✖
Centre Airbag	●	●	—
CHILD PROTECTION			
Isofix/i-Size	—	●	●
Integrated CRS	—	✖	✖
Airbag cut-off switch	—	●	—
SAFETY ASSIST			
Seat Belt Reminder	●	●	●

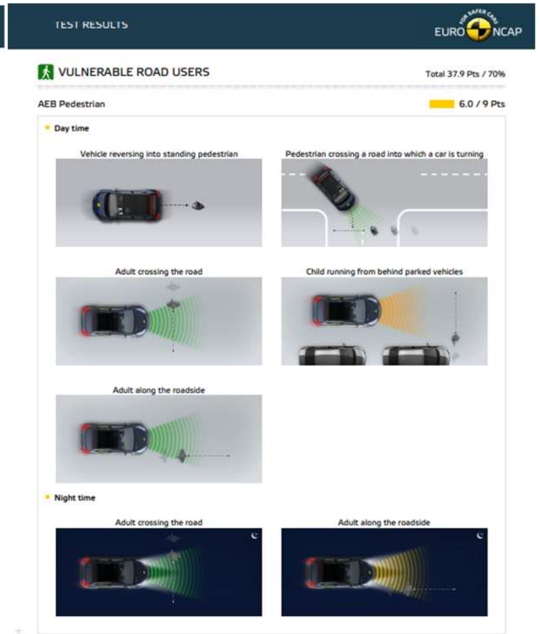
OTHER SYSTEMS	
Active Bonnet	✖
AEB Vulnerable Road Users	●
AEB Pedestrian - Reverse	✖
AEB Car-to-Car	●
Speed Assistance	●
Lane Assist System	●

Note: Other equipment may be available on the vehicle but was not considered in the test year.

● Fitted to the vehicle as standard ○ Fitted to the vehicle as part of the safety pack

○ Not fitted to the test vehicle but available as option or as part of the safety pack ✖ Not available — Not applicable





Comments

The passenger compartment of the EC40 remained stable in the frontal offset test. Protection of all critical body areas was good for both driver and front passenger and the EC40 scored maximum points in this part of the assessment. Volvo showed that a similar level of protection would be provided to the knees and femurs of occupants of different sizes and to those sitting in different positions. Analysis of the deceleration of the impact trolley during the test, and analysis of the deformable barrier after the test, revealed that the EC40 would be an aggressive impact partner in a frontal collision. With the exception of the chest of the rear passenger, protection of which was adequate, all critical body areas of both the driver and rear seat passenger were well protected. In both the side barrier test and the more severe pole impact, protection of all critical body areas was good and the car scored maximum points. Control of excursion (the extent to which a body is thrown to the other side of the vehicle when it is hit from the far side) was found to be adequate. The EC40 has a counter-measure to mitigate against occupant to occupant injuries in such impacts and this performed well in Euro NCAP's test. Tests on the front seats and head restraints demonstrated good protection against whiplash injuries in the event of a rear-end collision. A geometric analysis of the rear seats also indicated good whiplash protection. The EC40 has an advanced eCall system which alerts the emergency services in the event of a crash. The car also has a system which applies the brakes after an impact, to avoid secondary collisions.

https://www.euroncap.com/en/results/peugeot/3008/11055 ; https://www.euroncap.com/en/press-media/press-releases/eight-manufacturers-achieve-euro-ncap-5-stars-in-impressive-car-line-up/ ; https://insideevs.com/news/588028/volvo-c40-recharge-5star-euro-ncap/

Types and examples of automotive testing

- Compliance
  - The United Nations Economic Commission for Europe (UN-ECE) regulations play a crucial role in ensuring that vehicles meet specific safety, environmental, and performance standards before they can be sold in the market. Several key UN-ECE regulations are mandatory for vehicles to be certified for road use, such as:
    - UN Regulation No. 13: Requirements for braking systems.
    - UN Regulation No. 94: Occupant protection in the event of a frontal collision.
    - UN Regulation No. 95: Protection of passengers in the event of a lateral collision.
    - UN Regulation No. 100: Electric powertrain vehicles' safety requirements.
    - UN Regulation No. 140: Electronic Stability Control (ESC) systems.
  - Vehicles that fail to meet these regulations cannot be sold in many countries, including the EU and other regions. These standards ensure that vehicles are safe, efficient, and environmentally friendly. Without adherence to these regulations, a vehicle cannot receive the necessary type approval certification (e-Mark), which is crucial for entering the market(UNECE)(TÜV SÜD).

https://unttc.org/partners/ece/unctad ;

Types and examples of automotive testing

- Compliance
  - UN Regulation No. 13: Requirements for braking systems.

Braking tests and performance of braking systems

1. Braking tests

1.1. General

1.1.1. The performance prescribed for braking systems is based on the stopping distance and the mean fully developed deceleration. The performance of a braking system shall be determined by measuring the stopping distance in relation to the initial speed of the vehicle and/or by measuring the mean fully developed deceleration during the test.

1.1.2. The stopping distance shall be the distance covered by the vehicle from the moment when the driver begins to actuate the control of the braking system until the moment when the vehicle stops; the initial speed shall be the speed at the moment when the driver begins to actuate the control of the braking system; the initial speed shall not be less than 98 per cent of the prescribed speed for the test in question.

The mean fully developed deceleration (d_m) shall be calculated as the deceleration averaged with respect to distance over the interval v_b to v_e, according to the following formula:

$$d_m = \frac{v_b^2 - v_e^2}{25{,}92\ (S_e - S_b)}$$

Where:

v_o = initial vehicle speed in km/h,

v_b = vehicle speed at 0,8 v_o in km/h,

v_e = vehicle speed at 0,1 v_o in km/h,

s_b = distance travelled between v_o and v_b in metres,

s_e = distance travelled between v_o and v_e in metres.

The speed and distance shall be determined using instrumentation having an accuracy of ± 1 per cent at the prescribed speed for the test. The d_m may be determined by other methods than the measurement of speed and distance; in this case, the accuracy of the d_m shall be within ± 3 per cent.

1.2. For the approval of any vehicle, the braking performance shall be measured during road tests conducted in the following conditions:

1.2.1. The vehicle's condition as regards mass shall be as prescribed for each type of test and be specified in the test report;

Recommended: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:42023X0401

Types and examples of automotive testing

- Compliance
  - UN Regulation No. 13: Requirements for braking systems.

1.4. Type-0 test (ordinary performance test with cold brakes)

1.4.1. General

1.4.1.1. The average temperature of the service brakes on the hottest axle of the vehicle, measured inside the brake linings or on the braking path of the disc or drum, is between 65 and 100 °C prior to any brake application.

1.4.1.2. The test shall be conducted in the following conditions:

1.4.1.2.1. The vehicle shall be laden, the distribution of its mass among the axles being that stated by the manufacturer; where provision is made for several arrangements of the load on the axles the distribution of the maximum mass among the axles shall be such that the mass on each axle is proportional to the maximum permissible mass for each axle;

1.4.1.2.2. Every test shall be repeated on the unladen vehicle; there may be, in addition to the driver, a second person on the front seat who is responsible for noting the results of the test;

1.4.1.2.3. In the case of a vehicle equipped with an electric regenerative braking system, the requirements depend on the category of this system:

Category A. Any separate electric regenerative braking control which is provided, shall not be used during the Type-0 tests.

(1) The manufacturer shall provide the Technical Service with the family of braking curves permitted by the automatic control strategy. These curves may be verified by the Technical Service.

Recommended: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:42023X0401

Types and examples of automotive testing

- Compliance
  - UN Regulation No. 13: Requirements for braking systems.

1.5. Type-I test (fade and recovery test)

1.5.1. Heating procedure

1.5.1.1. The service brakes of all vehicles shall be tested by successively applying and releasing the brakes a number of times, the vehicle being laden, in the conditions shown in the table below:

Conditions

v_1 (km/h)	v_2 (km/h)	Δt (sec)	n
80 % $v_{max} \leq 120$	0,5 v_1	45	15

Where:

v_1 = initial speed, at beginning of braking

v_2 = speed at end of braking

v_{max} = maximum speed of the vehicle

n = number of brake applications

Δt = duration of a braking cycle: time elapsing between the initiation of one brake application and the initiation of the next.

Recommended: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:42023X0401

Types and examples of automotive testing

- Compliance
  - UN Regulation No. 13: Requirements for braking systems.

1.5.2. Hot performance

1.5.2.1. At the end of the Type-I test (described in paragraph 1.5.1. of this annex) the hot performance of the service braking system shall be measured in the same conditions (and in particular at a mean control force no greater than the mean force actually used) as for the Type-0 test with the engine disconnected (the temperature conditions may be different).

1.5.2.2. This hot performance shall not be less than 75 (2) per cent of that prescribed, nor less than 60 per cent of the figure recorded in the Type-0 test with the engine disconnected.

1.5.2.3. For vehicles fitted with an electric regenerative braking system of category A, during brake applications, the highest gear shall be continuously engaged and the separate electric braking control, if any, not used.

1.5.2.4. In the case of vehicles equipped with an electric regenerative braking system of category B, having carried out the heating cycles according to paragraph 1.5.1.6. of this annex, the hot performance test shall be carried out at the maximum speed which can be reached by the vehicle at the end of the brake heating cycles, unless the speed specified in paragraph 2.1.1.(A) of this annex can be reached.

For comparison, a later Type-0 test with cold brakes shall be repeated from this same speed and with a similar electric regenerative braking contribution, as set by an appropriate state of battery charge, as was available during the hot performance test.

Following the recovery process and test, further reconditioning of the linings shall be permitted before the test is made to compare this second cold performance with that achieved in the hot test, against the criteria of paragraphs 1.5.2.2. or 1.5.2.5. of this annex.

The tests may be conducted without a regenerative braking component. In this case, the requirement on the state of charge of the batteries is not applicable.

1.5.2.5. In the case of a vehicle which satisfies the 60 per cent requirement specified in paragraph 1.5.2.2. of this annex, but which cannot comply with the 75 (2) per cent requirement of paragraph 1.5.2.2. of this annex, a further hot performance test may be carried out using a control force not exceeding that specified in paragraph 2. of this annex. The results of both tests shall be entered in the report.

(2) This corresponds to a stopping distance of $0,1\ v + 0,0080\ v^2$ and a mean fully developed deceleration of $4,82\ m/s^2$.

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Test frameworks

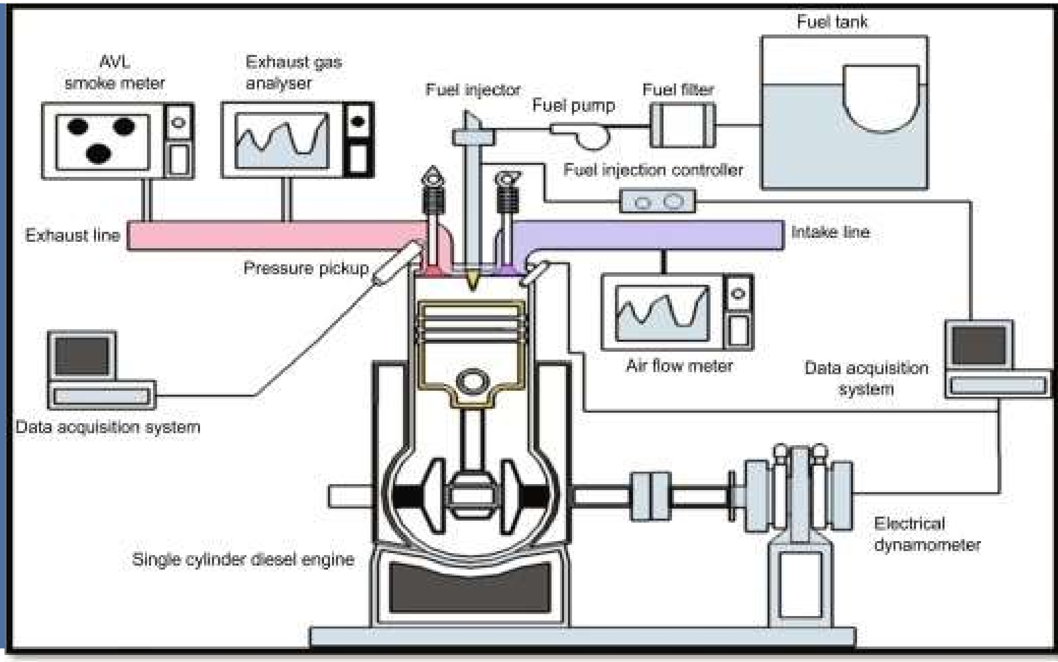
- Bench
- Simulation and modelling
- Prototyping
- Field testing

Test frameworks

- Bench
  - Testing individual components or subsystems in a controlled environment, often before full integration into the vehicle.
  - Validate functionality, safety, and performance under simulated operating conditions.
  - Examples:
    - **Engine Bench Testing:** Evaluates engine performance (torque, emissions) without the vehicle.
    - **Battery Bench Testing:** Tests battery performance under different loads and environmental conditions.
- Simulation and modelling
- Prototyping
- Field testing

Test frameworks

- Engine Bench Testing



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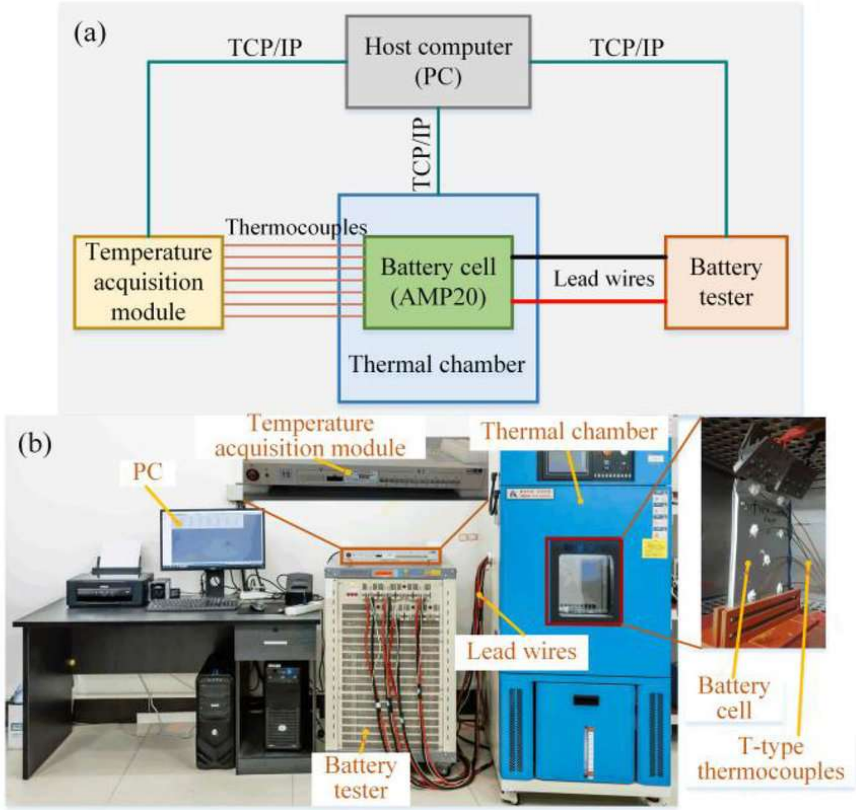
Test frameworks

- Battery Bench Testing



https://www.avl.com/en/testing-solutions/e-mobility-testing/battery-testing/avl-battery-module/pack-ts; https://www.researchgate.net/figure/Battery-testing-system-a-Schematic-diagram-b-Experimental-devices_fig4_348833746 ;

Test frameworks

- Bench
- Simulation and modelling
  - Virtual testing using software models to predict how components or systems will perform under various conditions.
  - Save time and cost by identifying issues before physical testing.
  - Examples:
    - CFD (Computational Fluid Dynamics): Used to simulate airflow and optimize aerodynamics.
    - Finite Element Analysis (FEA): Assesses structural integrity under stress or crash scenarios.
- Prototyping
- Field testing

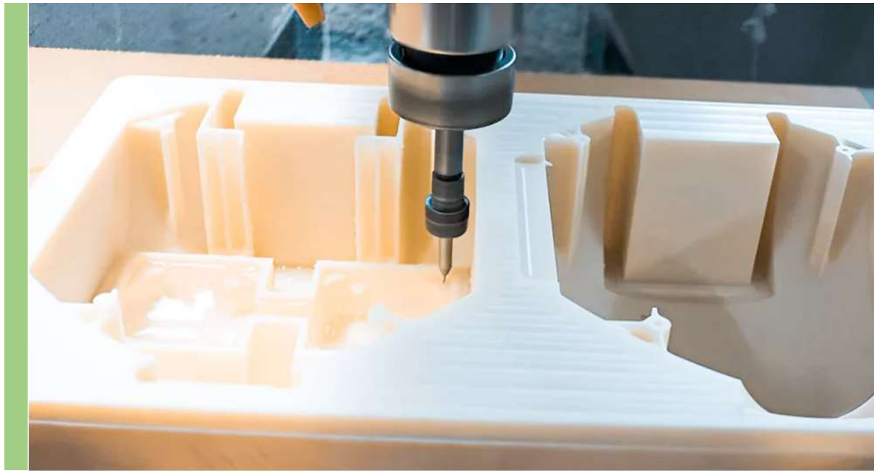
Test frameworks

- Bench
- Simulation and modelling
- Prototyping
  - Building and testing a physical version of the vehicle or component to validate design.
  - Verify if the actual product meets design specifications.
  - Example:
    - Testing a physical prototype for ride comfort, handling, and safety.
- Field testing

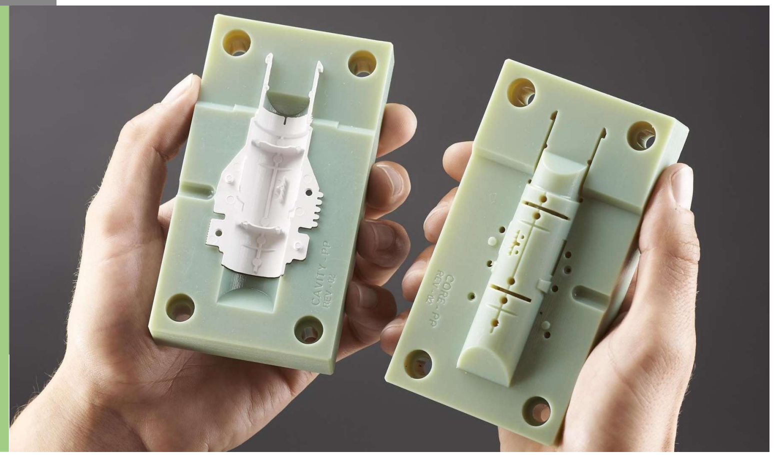
Test frameworks

- Prototyping
  - Prototyping in the automotive industry involves several methods, each serving different purposes in the design and development process.
  - Key prototyping procedures - manufacturing:
    - **CNC Machining:** This method is used to create precise and detailed prototypes from materials such as metal or plastic. CNC (Computer Numerical Control) machines can produce high-quality components, making this method suitable for performance parts like pistons and brake disks.
    - **3D Printing:** A rapid prototyping technique that allows for the creation of three-dimensional objects directly from CAD models. It is flexible and fast, making it ideal for small batches or custom parts. While it might not achieve the same surface finish as other methods, it is excellent for creating complex geometries.
    - **Vacuum Casting:** This involves creating silicone molds to produce parts, typically used for rubber and plastic components. It's a suitable method for rapid prototyping, providing high-quality surfaces and allowing for quicker production than traditional methods.
    - **Injection Molding:** Though traditionally seen as a mass production method, it is increasingly used in prototyping for its ability to produce high-quality plastic parts. Modern techniques have reduced lead times, allowing for quicker testing of designs.

Test frameworks



- Prototyping



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Test frameworks

- Prototyping
  - Prototyping in the automotive industry involves several methods, each serving different purposes in the design and development process.
  - Key prototyping procedures - phases:
    - **Proof-of-Concept Prototypes:**
      - Created in the initial design stages, these prototypes test whether an idea can work in practice. They are typically made from standard parts and are less refined, focusing on functionality rather than aesthetics.
    - **Design Validation Prototypes:**
      - Closer to the final product, these prototypes are built using the same materials and processes that will be used in mass production. They are critical for testing the design's viability and performance before full-scale manufacturing begins.
    - **Safety Testing Prototypes:**
      - These prototypes undergo rigorous testing to evaluate safety and durability. Techniques like Failure Mode Effect Analysis are employed to identify potential issues before the product reaches consumers.

Test frameworks

- Field testing
  - Real-world testing under normal and extreme operating conditions.
  - Ensure vehicle durability, performance, and safety in actual environments.
  - Example:

https://dewesoft.com/blog/how-are-adas-systems-and-autonomous-vehicles-tested

Test frameworks

Field testing

- Testing is conducted under extreme weather conditions to evaluate how electric vehicles (EVs) perform in different environments, such as arctic cold, desert heat, and high-altitude locations.
- To assess the impact of temperature variations on battery performance, energy efficiency, range, charging time, and thermal management systems.
- Procedures Involved:
  - Cold Climate Testing: Evaluates how sub-zero temperatures affect the battery's energy storage, charging capabilities, and the vehicle's cabin heating efficiency.
  - Hot Climate Testing: Examines battery cooling systems, motor overheating risks, and air conditioning load on energy consumption in temperatures that can reach up to 50°C.
  - High-Altitude Testing: Tests the vehicle's powertrain and battery efficiency when driving in low-oxygen conditions, typical of mountainous terrains.
- Outcome: Identifies potential performance degradation and failure points, enabling engineers to fine-tune battery management systems, optimize software algorithms, and improve insulation techniques to maintain consistent vehicle performance across diverse environmental conditions.

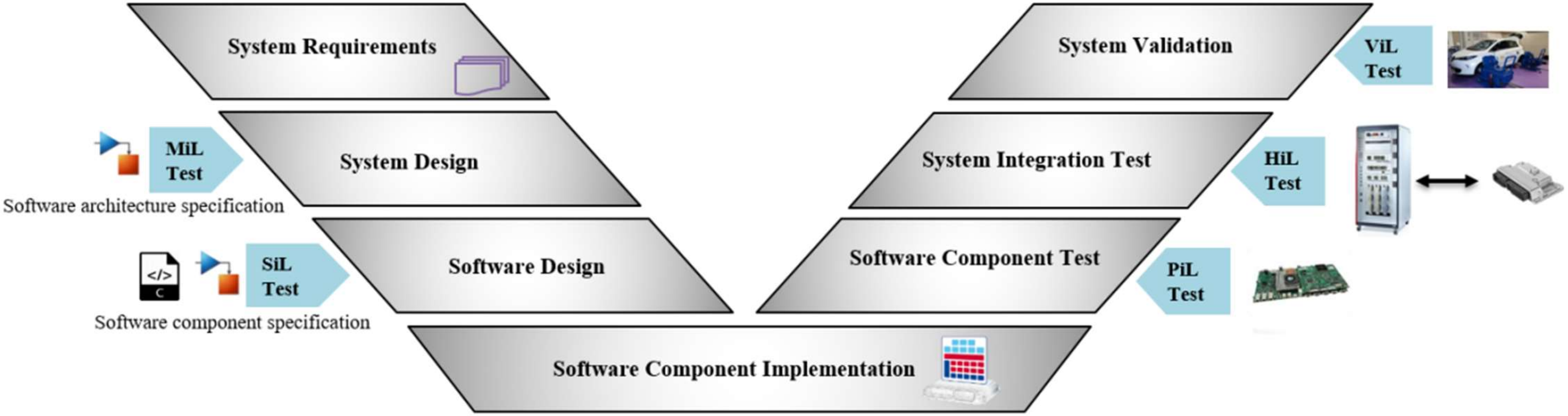
Testing methodologies for system level testing

- Model-in-the-Loop (MIL)
  - A testing method where control algorithms or software components are tested using a fully simulated model of the vehicle and its environment.
  - Purpose: To verify control strategies early in development, using simulations to catch errors before real-world testing.
  - Example: Testing an advanced traction control algorithm in MATLAB/Simulink, where both the algorithm and vehicle behavior are modeled mathematically. No physical components are involved.
- Software-in-the-Loop (SIL)
  - Testing where the actual controller code, written in languages like C or C++, is integrated into the simulation. This allows for testing the software's behavior under different conditions.
  - Purpose: To ensure the compiled software works correctly with the modeled vehicle systems, identifying issues related to code execution.
  - Example: Running engine control unit (ECU) software on a computer while simulating engine behavior, making sure the code executes as intended.
- Processor-in-the-Loop (PIL)
  - Testing the compiled software on the actual microcontroller or processor that will be used in the final product.
  - Purpose: To measure the software's real-time performance and ensure compatibility with the processor hardware.
  - Example: Running the ECU software on a development board with the same microcontroller as the production ECU, while interfacing with a simulation environment.

Testing methodologies for system level testing

- Hardware-in-the-Loop (HIL)
  - Involves testing the actual hardware components (like an ECU) with simulated vehicle dynamics. The hardware interfaces with sensors and actuators that are simulated, allowing realistic testing without needing a full vehicle.
  - Purpose: To validate that hardware interacts correctly with the vehicle's systems and can handle real-time operation.
  - Example: Testing a brake control system ECU using a simulation rig that mimics sensor inputs and actuator feedback for various road conditions.
- Vehicle-in-the-Loop (VIL)
  - Testing a real vehicle while integrating virtual or simulated elements. This setup combines physical and virtual testing environments to replicate various driving scenarios.
  - Purpose: To test vehicle behavior in a controlled environment with realistic scenarios, especially useful for testing safety features or autonomous systems.
  - Example: Placing an electric vehicle on a chassis dynamometer and simulating different driving conditions like uphill or downhill to optimize energy management systems.
- Driver-in-the-Loop (DIL)
  - Involves a human driver interacting with either a real vehicle or a high-fidelity simulator to test driving dynamics, control systems, or driver assistance features.
  - Purpose: To evaluate how a human interacts with the vehicle systems and validate driver-related features.
  - Example: A driving simulator used to test the effectiveness of adaptive cruise control or lane-keeping assistance.

Testing methodologies for system level testing



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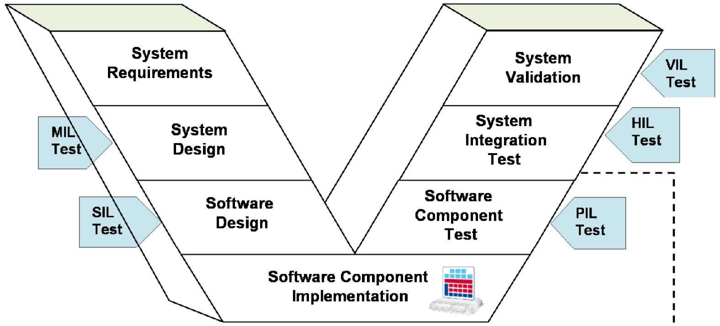

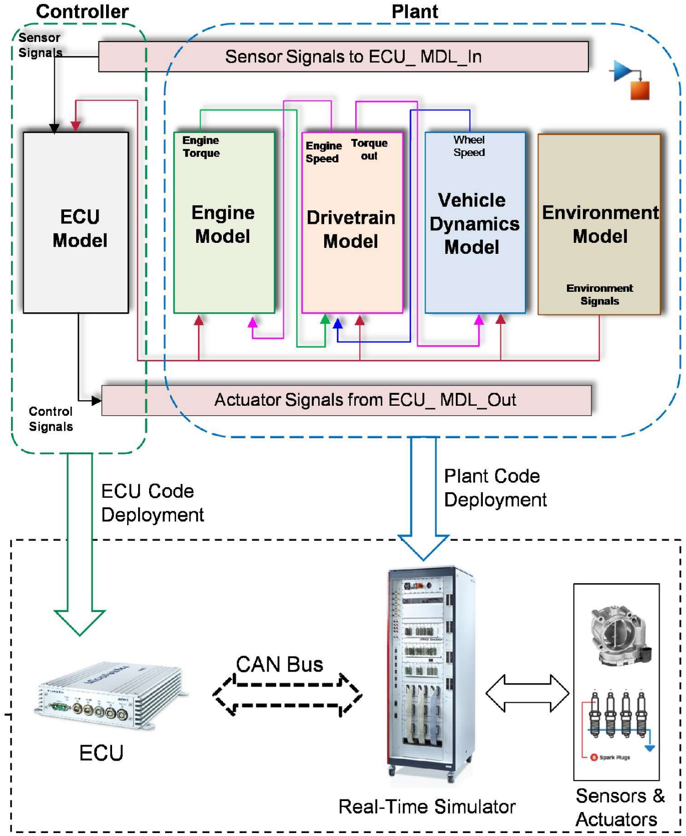

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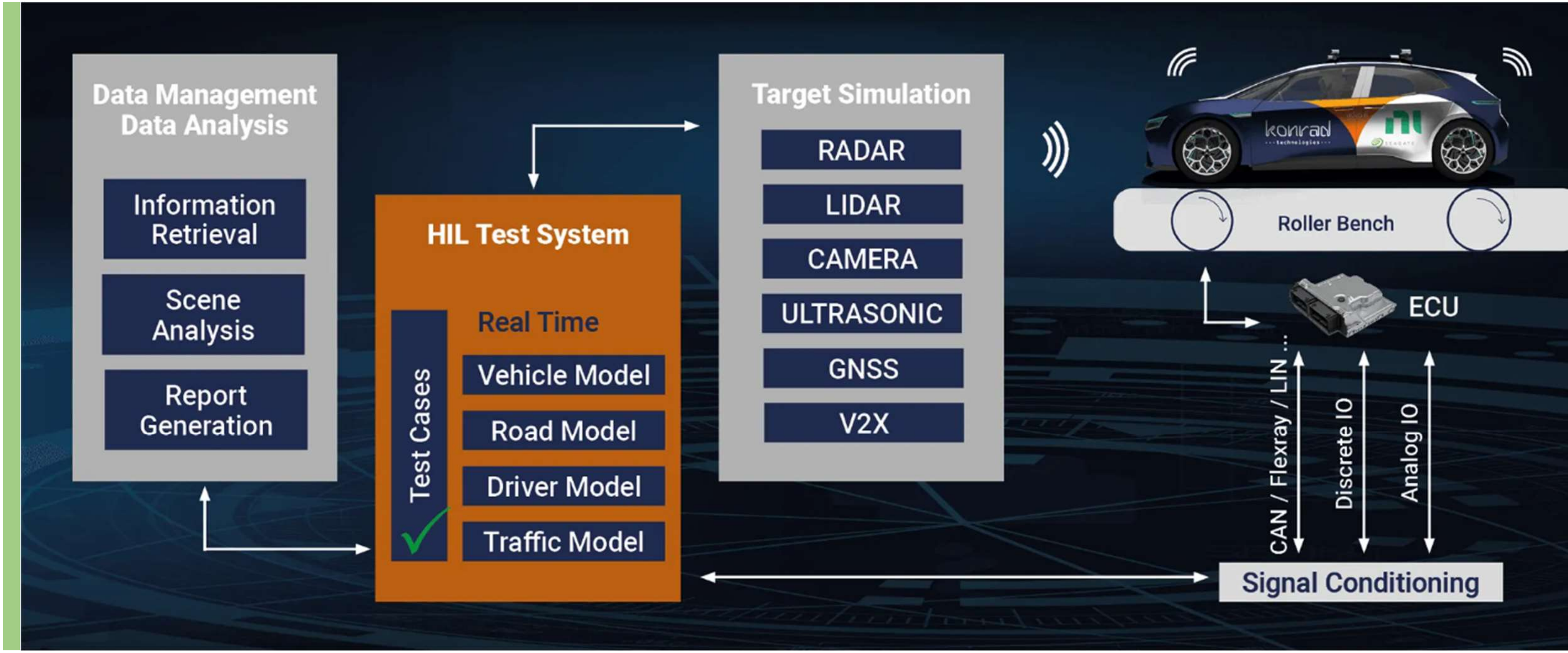
Testing methodologies for system level testing



Vehicle-in-the-loop

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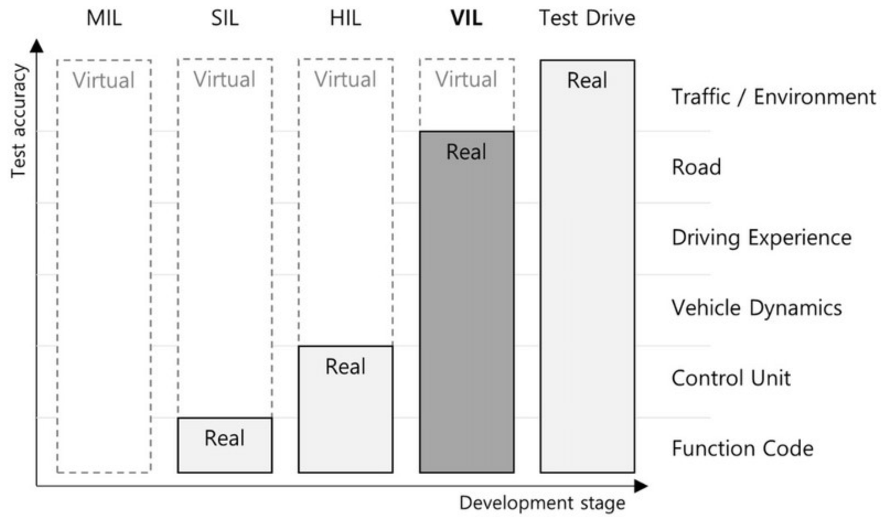

https://www.researchgate.net/figure/MIL-vs-SIL-vs-HIL-vs-VIL-vs-Test-Drive_fig1_340605747 ;

Testing methodologies for system level testing

Test Case	MIL	SIL	PIL	HIL	VIL	DIL
Only ECU participates in measurement	✓	✓	✓	✓		
Only a stub axle participates in measurement		✓	✓	✓		
Only a sensor participates in measurement		✓	✓	✓		
The entire vehicle participates in measurement				✓	✓	✓
Only the engine participates in measurement	✓	✓	✓	✓		
Only the drivetrain participates in measurement		✓	✓	✓		
Only the braking system participates in measurement		✓	✓	✓		
Only the suspension participates in measurement		✓	✓	✓		
Driver interaction testing (DIL)					✓	✓
Real-world condition testing					✓	✓
Real-time performance monitoring			✓	✓		✓
Fault handling testing		✓	✓	✓		✓

Q & A

- Main objective?
- Starting point-ending point?
- Complex parts?
- Less relevant part(s), could be omitted part(s)?
- Most useful part(s)?

Closing

- Bibliography
  - See bottom of slides
  - Tervezéselmélet és módszertan (BMEGEGE MGTM) Előadások Dr. Horák Péter BME GT3 Tanszék 2010
- Literature
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  - Julian Weber - The Automotive Development Process: Processes for Successful Customer Oriented Vehicle Development
  - Markus Maurer, Hermann Winner - Automotive Systems Engineering
  - Christian Grönroos - The V-Model of Service Quality: An Application in Automotive Services
  - Gerhard Pahl, Wolfgang Beitz - Engineering Design: A Systematic Approach
  - Jiju Antony - Design of Experiments for Engineers and Scientists
  - Dominic Haider - Automotive Functional Safety: A Complete Guide to ISO 26262
  - Bercsey Tibor - A terméktervezés módszertana.Jegyzet
  - Pahl-Beitz - A géptervezés elmélete és gyakorlata


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Thank you for your attention!