System level testing

Lecture 8

Schedule

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	Prototype racecar investigation in workshop		6	Lab	
7	10.16.	T1	Midterm exam I.				
8	10.23.	B	National holiday				
9	10.30.	-	-		T1 R	Exam 1 - Retake	
10	11.06.	7	Testing strategies in the automotive industry		7	Lab	
11	11.13.	8	System level testing & Performance and reliability testing		8	Lab	
12	11.20.	9	Troubleshooting and error calculation & Project management		9	Lab	
13	11.27.	T2	Midterm exam II.				
14	12.04.	T2R	Project presentation		T2 R	Exam 2 - Retake	

Semester requirements

3. Félévi jegy

A jegy az egyetemi vonatkozó szabályzatok figyelembevételével alakul ki.

1. ZH1 25p (min 40% elérése kötelező)
2. ZH2 25p (min 40% elérése kötelező)
3. Projekt 50p (min 40% elérése kötelező)
    i. Dokumentáció formai követelmények 5p
    ii. Dokumentáció szakmai színvonala 25p (min 40% elérése kötelező)
    iii. Féléves haladás, projektmunka 15p
    iv. Prezentáció 5p

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- Introduction to System level testing
- Overview of automotive systems
  - Powertrain
  - Chassis
  - Electrical
  - Infotainment
  - Safety and driver assistance
- Types of system level testing
  - Integration
  - Functional
  - Performance
  - Safety
  - Reliability and durability
- Bench testing

Introduction to System Level Testing

- **Definition:** System-level testing in the automotive industry refers to the process of validating the performance, reliability, and integration of entire systems within a vehicle, rather than testing individual components in isolation.

- **Objectives:**
  - Ensure seamless operation between interconnected systems (e.g., powertrain with ADAS).
  - Identify and address system-level issues early in the development process.
  - Validate that the vehicle meets all design, safety, and regulatory requirements.

- **Why It Matters:**
  - Modern vehicles are complex, with integrated software and hardware components. System-level testing helps prevent compatibility and performance issues that might not be visible when components are tested individually.
  - Supports comprehensive quality assurance, leading to safer, more reliable vehicles.

- **Example Case:** Consider a new hybrid vehicle. System-level testing ensures that the interaction between the electric and combustion engines, battery management system, and transmission functions cohesively across different driving conditions.

Introduction to System Level Testing

- Example: Toyota Hybrid Braking Problem

An owner from Alabama states:

"At random times, when traveling at 10-15 mph and applying the brakes to stop or slow, the brakes will slip for a second or less and then re-engage. Never experienced this before with 2 other Toyota hybrids I have owned. Scary feeling. Have notified Toyota Customer service since I have read others with (the) same model (Highlander Hybrid Platinum) have (the) same problem."

This same owner stated in a forum that the SUV was only two months old.

"It seems to happen when I'm braking to stop at an intersection and I'm driving at a decline (like going downhill). It doesn't happen every time, so it is hard to reproduce the problem. The service center at my dealership said that there were no malfunction codes when I took it in to be serviced. Nonetheless, this has caused me enough concern that I've submitted a complaint with NHTSA and to Toyota corporate office. Something should be done about this before someone gets hurt."

An owner from New York states:

"My new 2021 Toyota highlander hybrid (is) having random issues when braking. I notice most of the time when the car is going downhill, the car will lose braking for a second and I have to depress the brake harder to slow the vehicle. In that second when it loses the brake the car is actually going forward, which can cause unpredictable stopping distance."

This owner is worried that it may cause an accident if following too close to a vehicle in front. The complaint goes on to say that there is no warning light displayed on the dashboard and it isn't possible to reproduce the problem. "It can happen randomly."

An owner from Indiana states:

"The Highlander Hybrid is dangerous and someone will get hurt. The brakes will occasionally, at lower speeds and under a variety of circumstances, stop working for a second or two. It actually gives the feeling that the car is accelerating or surging forward.

"My dealer was able to replicate the problem but said they hadn't heard of a fix yet. They had heard of this issue from several customers. Toyota maintains it is normal operation and is simply the hybrid switching from regenerative braking to mechanical braking. It is completely unpredictable. Sometimes it will go a week without happening. Sometimes it will happen several times in 1 day.

"My wife and I do not feel safe in this car. Very frustrating that Toyota doesn't seem to take this seriously. It's simply a matter of time before we rear end someone, or hit something else."

https://lemberglaw.com/toyota-highlander-brake-problems/ ;

Introduction to System Level Testing

- **Example: Toyota Hybrid Braking Problem**
- **Description of the Issue**: In Toyota hybrid models, such as the Prius, there was an issue with the integrated braking system where a delay or insensitivity occurred during the transition between regenerative braking and traditional hydraulic braking. This kind of problem could have been identified during system-level testing that evaluates the joint operation of various systems (electric drive and hydraulic braking).
- **Consequence**: The malfunction caused the braking system to respond inadequately, increasing stopping distances and posing a potential safety risk. Such issues point to gaps in system-level testing or limitations in testing scenarios.
- **Lesson Learned**: This example highlights the importance of thorough system-level testing, particularly in hybrid and electric vehicles where multiple technologies (software, electrical, and mechanical systems) need to function cohesively to ensure safe and reliable operation.

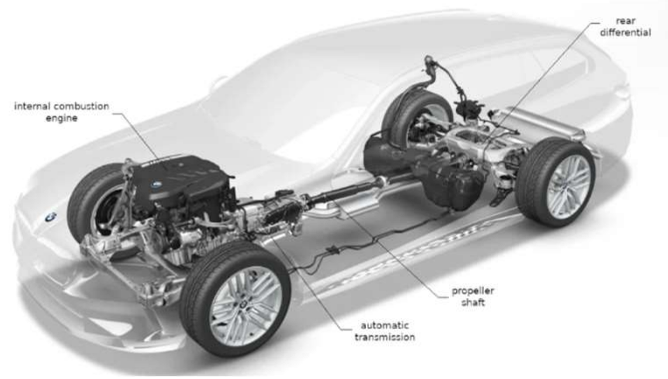
Overview of Automotive Systems

- Automotive systems encompass a wide range of interconnected components and technologies, each playing a critical role in vehicle functionality, safety, and performance.

- Key Automotive Systems:
  1. Powertrain System
  2. Chassis System
  3. Electrical/Electronic System
  4. Infotainment System
  5. Safety and Driver Assistance System

https://www.kenstrans.com/what-are-the-main-systems-of-a-car/ ;

Overview of Automotive Systems



1. **Powertrain System:**
   1. **Function**: Converts energy (fuel or electricity) into mechanical power to propel the vehicle.
   2. **Components**: Engine (ICE or electric motor), transmission, drivetrain.
   3. **Example**: Hybrid powertrains, combining a combustion engine with an electric motor for improved efficiency.
2. **Chassis System:**
   1. **Function**: Provides structural support and houses various mechanical components.
   2. **Components**: Chassis, suspension, steering, braking system.
   3. **Example**: Advanced suspension systems in luxury vehicles for enhanced ride comfort.
3. **Electrical/Electronic System:**
   1. **Function**: Powers and controls the vehicle's electronic features, including infotainment, lighting, and power windows.
   2. **Components**: Battery, alternator, wiring harness, electronic control units (ECUs).
   3. **Example**: Modern ECUs that manage engine control, ADAS, and cabin features.

https://x-engineer.org/powertrain-vs-drivetrain/ ;

Overview of Automotive Systems

4. **Infotainment System:**
    1. **Function**: Provides entertainment, navigation, and connectivity features to enhance the user experience.
    2. **Components**: Touchscreen displays, audio systems, GPS modules.
    3. **Example**: Apple CarPlay and Android Auto integration for seamless smartphone connectivity.

5. **Safety and Driver Assistance System:**
    1. **Function**: Ensures driver and passenger safety, assists with driving tasks, and prevents accidents.
    2. **Components**: Airbags, seatbelt systems, ADAS (e.g., lane-keeping assist, automatic emergency braking).
    3. **Example**: Adaptive cruise control that adjusts the vehicle's speed based on traffic conditions.

https://futuremobilitymedia.com/adas-and-infotainment-increase-the-adoption-of-automotive-future-market-insights/ ;

Overview of Automotive Systems

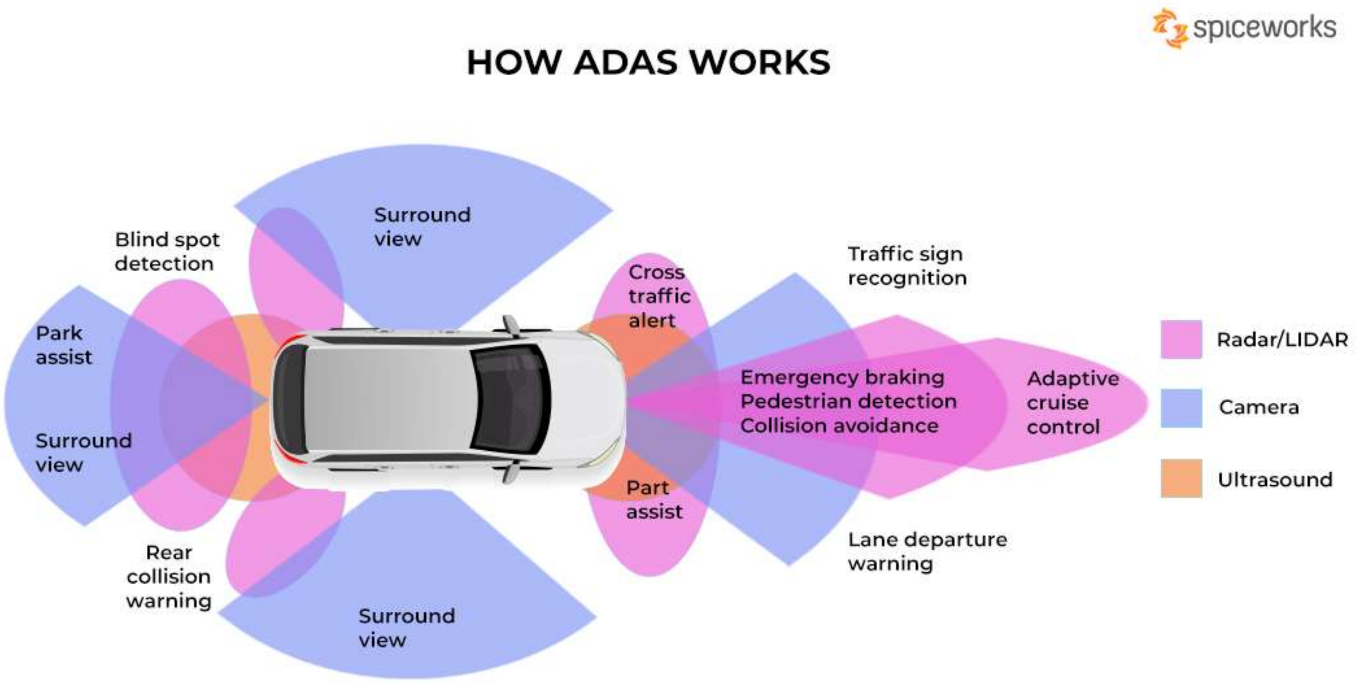
ADAS

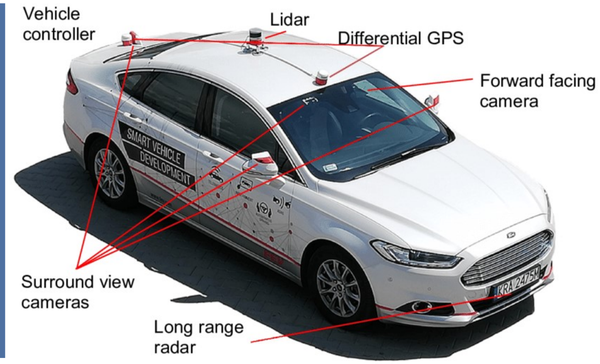
- **Definition:** Advanced Driver Assistance Systems (ADAS) are integrated technologies designed to improve vehicle safety and driving experience by assisting drivers in the decision-making process and controlling certain vehicle functions.

- **Key Functions of ADAS**:
  - **Collision Avoidance**: Automatic emergency braking to prevent rear-end collisions.
  - **Lane-Keeping Assistance**: Detects road markings and helps keep the vehicle centered in its lane.
  - **Adaptive Cruise Control**: Maintains a safe distance from the vehicle ahead by adjusting speed.
  - **Blind Spot Detection**: Alerts the driver to vehicles in their blind spots to prevent side collisions.
  - **Parking Assistance**: Assists with parallel or perpendicular parking through cameras and sensors.
  - **Technologies Involved**:
    - **Sensors**: Cameras, radar, LIDAR, ultrasonic sensors.
    - **Software**: Algorithms for data interpretation and decision-making.
    - **Connectivity**: Some systems integrate vehicle-to-vehicle (V2V) communication for additional safety.

Overview of Automotive Systems

ADAS

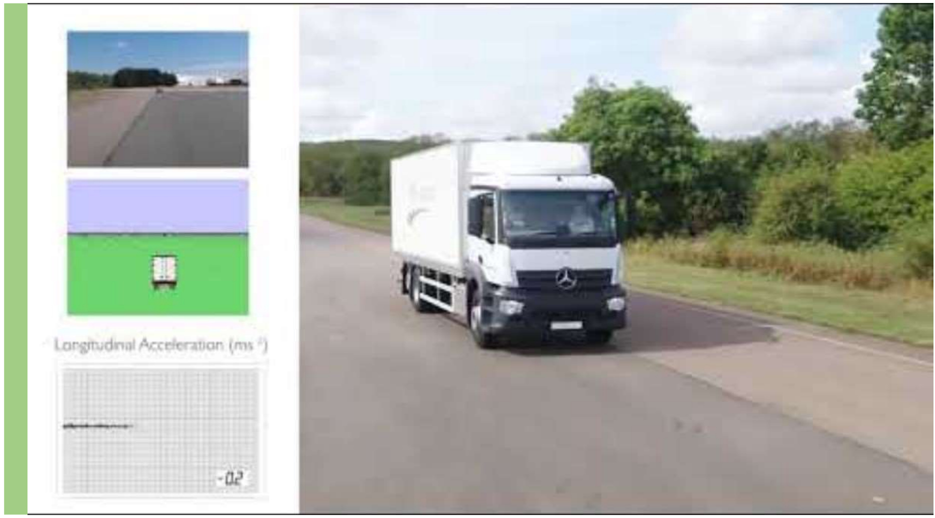




https://www.spiceworks.com/tech/iot/articles/what-is-adas/ ; https://www.researchgate.net/figure/The-positions-of-sensors_fig3_328227731 ;

Overview of Automotive Systems

ADAS



- Testing ADAS
  - Simulated Testing:
    - Virtual Environments: Use of software tools to create scenarios that test ADAS response (e.g., sudden pedestrian crossing).
  - Track Testing:
    - Controlled Scenarios: Vehicles are tested on private tracks for repeatable and measurable results.
    - Examples: Evaluating adaptive cruise control on a test track with variable-speed vehicles.
  - Real-World Testing:
    - Public Roads: Testing in real traffic conditions to capture unpredictable behaviors and edge cases.

- Challenges in ADAS Testing
  - Complex Scenarios: Difficulty in replicating rare, high-risk situations in a controlled environment.
  - Weather Conditions: Ensuring ADAS works reliably in rain, fog, snow, and varying light conditions.
  - Data Accuracy: Dependence on sensor accuracy and real-time data processing for correct decisions.
  - Integration with Other Systems: Making sure ADAS works smoothly with the vehicle's powertrain, braking, and steering.

- Takeaway: Robust testing strategies are essential to refine ADAS technologies, ensuring they meet safety standards and enhance user trust in automated systems.

Overview of Automotive Systems

ADAS

- Level 0: No Automation
  - **Description**: No automation. The driver is responsible for all driving tasks.
- Level 1: Driver Assistance
  - **Description**: The vehicle can assist with a single function (e.g., steering or speed control), but the driver must remain engaged and monitor the driving environment.
  - **Example**: Adaptive Cruise Control (ACC), Lane Keeping Assistance.
- Level 2: Partial Automation
  - **Description**: The vehicle can control multiple functions simultaneously (e.g., steering and acceleration), but the driver must still monitor the environment and be ready to intervene.
  - **Example**: Tesla Autopilot (steering and speed control working together).
- Level 3: Conditional Automation
  - **Description**: The vehicle can handle all driving tasks in certain conditions (e.g., highway driving), but the driver must be ready to take control when requested by the system.
  - **Example**: Audi Traffic Jam Pilot (autonomous driving on highways, driver must intervene if requested).
- Level 4: High Automation
  - **Description**: The vehicle can handle all driving tasks within specific environments (e.g., urban or parking scenarios) without driver intervention, but may require a human driver in other environments.
  - **Example**: Waymo (autonomous driving in certain city environments, no driver needed in specific conditions).
- Level 5: Full Automation
  - **Description**: Full autonomous driving. The vehicle performs all driving tasks in any environment and situation, with no need for human intervention.

Overview of Automotive Systems

BME Automotive Technologies

- Case Study: Tesla's Autopilot and other systems have faced criticism when ADAS failed to detect certain stationary objects or misinterpreted traffic conditions, highlighting the importance of comprehensive and continuous testing.

Overview of Automotive Systems

- Autopilot is Tesla's advanced driver assistance system that helps with driving tasks but still requires the driver's attention and intervention. Tesla currently offers two main packages: Autopilot and Full Self-Driving (FSD), each providing varying levels of automation.

- Autopilot (Basic Package)
  - **Adaptive Cruise Control (ACC)**: Automatically adjusts the vehicle's speed to maintain a safe distance from the car ahead.
  - **Lane Centering**: Keeps the car centered within the lane.
  - **Auto Lane Change**: Assists in changing lanes when the driver initiates the action.

- Full Self-Driving (FSD) (Advanced Package)
  - **Navigate on Autopilot**: Automatically steers the car on highways, including exit ramps, based on the navigation route.
  - **Autonomous Parking**: Allows the car to park itself in parallel or perpendicular spaces.
  - **Summon**: Enables the car to autonomously move in and out of parking spaces to meet the driver.
  - **Traffic Light and Stop Sign Recognition**: The car can recognize and react to traffic lights and stop signs, stopping and starting as needed.

- Challenges
  - Although Tesla's Autopilot and FSD systems are advanced, they still require the driver's attention, and full autonomy has not been fully achieved. In some situations, the system may not be able to handle complex or unexpected circumstances.
  - Testing and development of these systems are ongoing, as real-world variables such as environmental factors and traffic conditions present significant challenges in achieving full autonomy.
  - Tesla's Autopilot offers an advanced driver-assistance system, while the FSD package aims to take the vehicle closer to full autonomy, but still requires human oversight.

https://www.caranddriver.com/news/a35839385/tesla-autopilot-full-self-driving-autonomous-capabilities-tested-explained/ ;

Types of System Level Testing

- Integration Testing
- Performance Testing
- Safety Testing
- Reliability and Durability Testing

Types of System Level Testing

- Integration Testing
  - **Purpose:** Verifies the interaction between different systems or components within the vehicle, ensuring they work together smoothly as part of the overall system.
  - **Focus:** Ensures that subsystems (e.g., powertrain, electrical, safety, infotainment) interact correctly and reliably in the vehicle environment.
  - **Examples**:
    - Powertrain and Electrical System: Testing the communication between the engine control unit (ECU) and the battery management system (BMS) to ensure proper energy flow and efficiency in hybrid or electric vehicles.
    - Infotainment and Vehicle Controls: Ensuring the seamless interaction between the infotainment system and driver assistance features, such as using voice commands to adjust climate control or activate navigation.
    - Autonomous Driving Systems: Verifying the integration of sensors, cameras, and control units for accurate decision-making and real-time responses, such as when the vehicle switches from manual to autonomous mode.

Types of System Level Testing

- Integration Testing - Challenges
  - **Complex Interdependencies**

    Modern vehicles contain a large number of interconnected systems (e.g., powertrain, infotainment, braking systems). Ensuring these subsystems communicate correctly and do not interfere with each other requires extensive testing.
  - **Timing and Synchronization Issues**

    Real-time systems (e.g., engine management, braking systems) require precise timing for optimal performance. Delays or miscommunication can lead to safety risks or degraded performance.
  - **Compatibility and Version Control**

    Different subsystems may use different software versions or have varying hardware configurations. Ensuring compatibility and smooth integration across these versions is critical.
  - **Real-World Variability**

    Testing under varying conditions (temperature, humidity, road conditions, electromagnetic interference) is necessary to confirm that integration holds up across different environments.

Types of System Level Testing

- Integration Testing – Communication standards
  - CAN (Controller Area Network) *Up to 1 Mbps*

    The most common communication standard in automotive systems. It allows multiple ECUs (electronic control units) to communicate in real-time, ensuring the coordination of critical systems like powertrain, safety, and infotainment.
  - LIN (Local Interconnect Network) *20 kbps to 100 kbps*

    Used for lower-speed communication in non-critical systems (e.g., interior lighting, seat adjustment). LIN is often integrated with CAN for a full vehicle network solution.
  - FlexRay *10 Mbps*

    A higher-speed communication protocol used for more demanding applications, such as in safety systems (e.g., autonomous driving, airbag deployment) due to its higher fault tolerance and time-critical capabilities.
  - Ethernet *100 Mbps to 1 Gbps*

    Increasingly used in modern vehicles for high-bandwidth applications, such as infotainment systems and advanced driver assistance systems (ADAS), due to its fast data transfer rate.
  - MOST (Media Oriented Systems Transport) *25 Mbps to 150 Mbp*

    Used primarily for infotainment and multimedia applications, enabling the communication between audio, video, and control systems within the vehicle.

Types of System Level Testing

- Performance Testing
  - Purpose:
    - Evaluates the performance characteristics of the vehicle, ensuring it meets requirements for power, acceleration, handling, and efficiency.
  - Focus:
    - Verifies that the vehicle meets or exceeds specific performance criteria under both normal and extreme conditions.

Types of System Level Testing

- Performance Testing - Examples
  - Acceleration and Top Speed
    - Testing the time it takes for the vehicle to accelerate from 0 to 100 km/h (or other target speeds) to assess engine power, torque, and overall responsiveness.
    - Example: Testing a sports car's ability to reach its maximum speed on a closed track.
  - Braking Performance
    - Measuring braking distance and the vehicle's ability to maintain control during hard braking. This involves evaluating both dry and wet conditions.
    - Example: Testing emergency braking systems in various conditions (e.g., dry, wet, icy roads).
  - Fuel/Power Efficiency
    - Assessing fuel consumption or energy efficiency, such as liters per 100 km for traditional vehicles or kWh per 100 km for electric vehicles.
    - Example: Testing a hybrid vehicle's efficiency in city versus highway driving.
  - Handling and Stability
    - Evaluating how the vehicle performs in cornering, including tests for oversteer and understeer, as well as vehicle dynamics.
    - Example: Testing a vehicle's response to high-speed lane changes or sharp corners on a test track.
  - NVH (Noise, Vibration, and Harshness)
    - Measuring interior and exterior noise levels, vibration from the engine, and how harshly the vehicle handles road irregularities.
    - Example: Performing tests at various speeds and road conditions to assess cabin comfort and ride quality.

Types of System Level Testing

- Performance Testing – Challenges
  - Consistency Across Different Conditions
    - Ensuring that the vehicle's performance remains consistent across various environmental conditions, such as temperature, altitude, and humidity, which can affect engine output and aerodynamics.
  - Real-World Simulation
    - Designing tests that closely replicate real-world conditions (e.g., traffic, road quality, driver behavior) to provide meaningful results that match customer expectations.
  - Time and Resource Intensive
    - Performance tests, especially those involving high-speed or extreme conditions, can be resource-intensive, requiring dedicated facilities and controlled environments.
  - Data Collection and Analysis
    - The need for precise data collection using sensors and telemetry systems. Handling large volumes of data can be challenging when evaluating performance across various metrics simultaneously.

Types of System Level Testing

- Performance Testing – Methods
  - Track Testing
    - Using test tracks with specific routes designed to measure acceleration, braking, and handling performance in a controlled environment.
  - Road Testing
    - Testing the vehicle under real-world driving conditions, including various terrains and traffic scenarios, to assess its performance outside of controlled environments.
  - Simulation Testing
    - Virtual testing using simulation tools to predict the vehicle's performance under different conditions before physical testing. This method is increasingly used in automotive development due to its cost-effectiveness.
  - Endurance Testing
    - Long-duration testing to assess the vehicle's performance over extended periods, simulating the effects of wear and tear, and evaluating the reliability of key systems.

Types of System Level Testing

- Performance Testing – Case study WLTP
  - The WLTP is the standard for testing vehicle emissions, fuel consumption, and electric range, providing more accurate and realistic results compared to the NEDC.

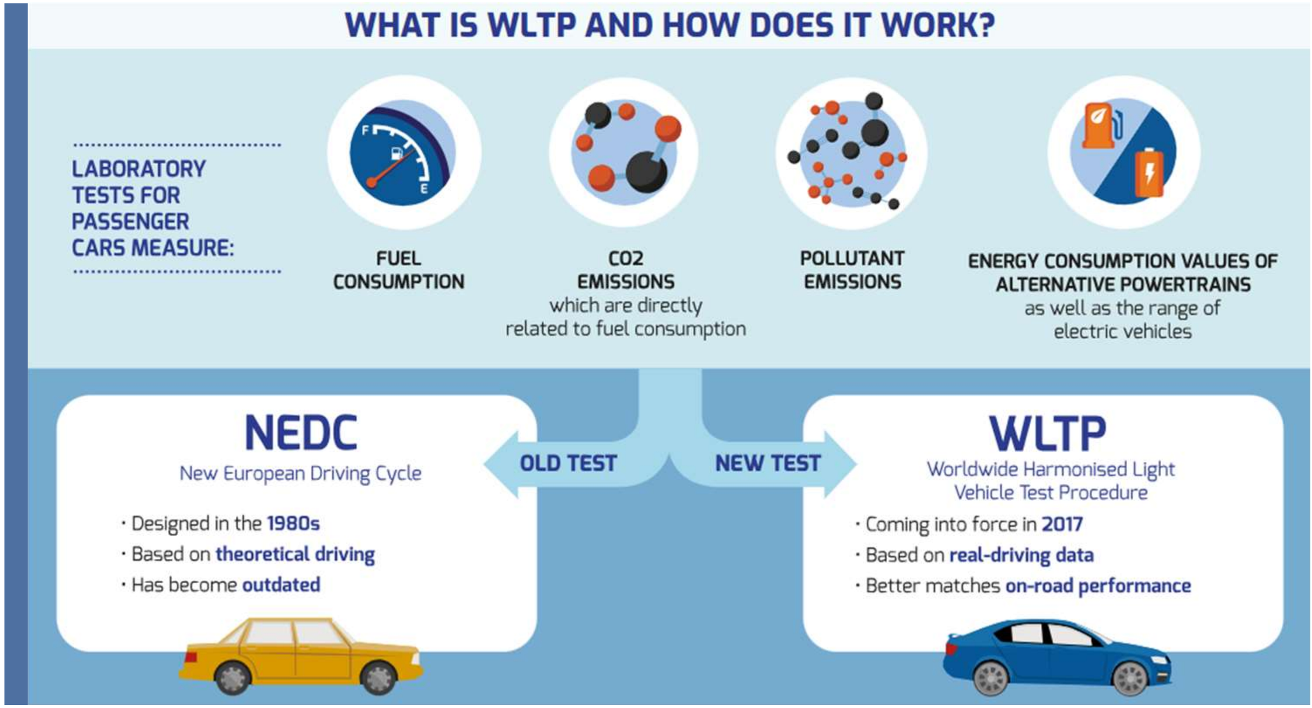
Driving Cycles Comparison

•**NEDC Example**: A 10 km loop with steady accelerations and decelerations, primarily at low and medium speeds.

•**WLTP Example**: Covers 23.25 km with varied driving phases:

- **Low Speed** (0–60 km/h): Simulates city traffic with frequent stops.
- **Medium Speed** (60–80 km/h): Mimics suburban driving.
- **High and Extra-High Speed** (up to 131 km/h): Represents highway conditions.

•*Real-World Impact*: A compact car tested under NEDC might show a consumption of 5.5 L/100 km, while under WLTP it could be 6.3 L/100 km due to more dynamic testing.



https://www.wltpfacts.eu/what-is-wltp-how-will-it-work/ ;

Types of System Level Testing

- Performance Testing – Case study ABAB

- **ABAB test method** is a testing approach used in motorsport development. The principle is to alternate between two different configurations (A and B) and measure their effects through separate test runs. The goal is to understand how specific changes, such as adjustments in settings or components, impact performance or other key factors, such as handling, stability, or acceleration.

- The **A-B-A-B** designation refers to the cycle where the test starts with configuration A, followed by configuration B, then back to A, and finally back to B. This approach ensures that the effects of different settings are measured objectively and consistently, minimizing the influence of external factors like weather or track conditions.

Run	Configuration	Description	Changes Made	Metrics to Measure	Driver Feedback	Lap Time	Remarks
1	A	Baseline handling test	Standard suspension	Lateral G-forces, steering input, lap time			Baseline performance
2	B	Handling test with modified setup	Stiffened suspension	Lateral G-forces, steering input, lap time			Compare with Run 1
3	A	Baseline handling test (repeated)	Return to standard suspension	Lateral G-forces, steering input, lap time			Compare with Run 1 and 2
4	B	Handling test with modified setup (repeated)	Return to stiffened suspension	Lateral G-forces, steering input, lap time			Final comparison with Run 1 and 2

https://blog.naver.com/cogram/221524768759 ;

Types of System Level Testing

- Safety Testing
  - **Purpose**
    Verifies that the vehicle's safety systems function correctly and reliably, ensuring the protection of the driver, passengers, and pedestrians under normal and extreme conditions.
  - **Focus**
    Evaluates the performance of safety-critical systems such as airbags, braking systems, collision avoidance, and driver assistance technologies, ensuring that they meet regulatory standards and real-world safety requirements.

Types of System Level Testing

- Safety Testing - Testing Methods

1. Physical Testing
   - **Example:** Full vehicle crash tests, sled tests, and impact simulations to analyze the car's structural and safety features.
2. Simulation Testing
   - **Example:** Using software and virtual simulations to model safety system responses, especially for testing scenarios that are difficult to replicate physically (e.g., extreme weather or rare accident scenarios).
3. Human Factors Testing
   - **Objective:** Evaluates how driver and passenger behavior affects safety, including seatbelt usage, driver attention levels, and the effectiveness of safety warnings.

Types of System Level Testing

- Safety Testing - Challenges in Safety Testing
  - **Variability in Testing Conditions**
    - **Environmental Factors:** Weather conditions, road surfaces, and lighting conditions (e.g., nighttime driving) significantly impact the performance of safety systems. Testing must simulate these variations to ensure reliable system responses in real-world scenarios.
    - **Example:** ADAS systems may not perform optimally in heavy rain or snow, requiring rigorous testing in a variety of environmental conditions to ensure reliability.
  - **Realistic Accident Simulation**
    - **Dynamic Testing:** Real-world accidents often involve complex interactions between multiple vehicles and pedestrians, making it difficult to replicate every scenario in physical testing. Testing must account for a wide range of crash angles, speeds, and impact combinations.
    - **Example:** Simulating a rear-end collision with a sudden stop at varying speeds or testing the effectiveness of airbags when a vehicle is struck from multiple angles.
  - **Testing for Rare Events**
    - **Rollover Protection Testing:** Testing a vehicle's ability to withstand a rollover, which is a rare but critical event, can be difficult to replicate in real-life scenarios.
    - **Example:** Specialized tests, such as tilt tests or dynamic rollover simulations, are conducted to ensure that the vehicle's roof strength and side-impact protection are sufficient.

https://navigator.innovation.ca/en/facility/national-research-council-canada/heavy-vehicle-tilt-research-facilities ;

Types of System Level Testing

- Reliability and Durability Testing
  - **Purpose:**
    To ensure that vehicle systems and components perform consistently over time and under various conditions without failure.
  - **Focus:**
    Reliability testing assesses the likelihood that systems will operate as intended over a specific time frame, while durability testing evaluates how systems withstand prolonged stress and environmental exposure over their lifecycle.

https://dewesoft.com/blog/what-is-durability-testing ;

Types of System Level Testing

Consistent performance under expected conditions

Extended periods or extrem conditions

- Reliability and Durability Testing - Key Components of Reliability and Durability Testing
- **Reliability Testing:**
  - **Objective:** Ensures that vehicle systems and components function correctly under normal usage without frequent breakdowns or malfunctions.
  - **Example:** Testing the reliability of an infotainment system by simulating continuous usage cycles over thousands of hours.
  - **Methods:**
    - **Accelerated Life Testing (ALT):** Simulates years of usage within a shorter timeframe to identify potential failure points.
    - **Environmental Stress Screening (ESS):** Subjects components to varying environmental conditions, such as temperature fluctuations, vibration, and humidity.
- **Durability Testing:**
  - **Objective:** Evaluates how components and systems withstand long-term stress, such as high mileage, heavy loads, or extreme operating conditions.
  - **Example:** Running an engine continuously at high RPMs for extended periods to assess long-term wear and tear.
  - **Methods:**
    - **Endurance Testing:** Simulates extended real-world driving conditions to ensure that systems like suspension, chassis, and drivetrain hold up over thousands of kilometers.
    - **Road Load Simulation:** Uses dynamometers or test tracks to replicate forces acting on a vehicle over rough roads, sharp turns, and varying terrains.

Types of System Level Testing

- Reliability & Durability Test cases:
  - Vibration testing
  - Thermal cycling
  - Drop and impact testing
  - Accelerated Life Testing (ALT)
  - Humidity and environmental testing
  - Immersion testing
    - IP rating
      - The IP rating (Ingress Protection rating) is a standard that defines the level of protection a device has against solids and liquids. It consists of two digits: the first indicates protection against solid objects like dust, and the second specifies resistance to water.
      - For example, an IP67-rated device is dust-tight (6) and can be submerged in water up to 1 meter for 30 minutes (7). This rating ensures that electronic equipment can withstand certain environmental conditions.

Road Load data captured by a Dewesoft DAQ system is replayed by an MTS "four poster" simulator to perform durability testing

Recommended: https://dewesoft.com/blog/what-is-durability-testing

Bench Testing

- Definition
  - Bench testing evaluates individual automotive systems in isolation to assess their performance and functionality.
- Purpose
  - To identify potential issues and refine system design before vehicle integration.

Vehicle Testing

- Different test track scenarios, such as slalom courses for handling tests.
- Public road testing for software like ADAS, where real-world challenges can be encountered.
- Nürburgring track as an extreme testing ground for performance cars and its impact on refining suspension and handling.
- Next lecture...

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
  - W. Ernst Eder: Engineering Design: Role of Theory, Models, and Methods
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