

# Middleware Diagnostics in Automotive Vehicles for Different Architectures

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Middleware diagnostics form an essential part of designing any truck, car, or another mobile vehicle, which in today's world comprises hardware with software functionality.

Middleware in any vehicle consists of the software or the OS (Operating System) which forms the base Hypervisor and connects with other Electronic Control Units (ECUs) together with the subsequent applications layers and drivers. Communication protocols of Controller Area Network and Ethernet (sometimes LIN Linear Interconnection Network) are used. This report highlights the overview level as to how this middleware functionality was achieved in classic architecture ECUs which had mostly powertrain functionality and has evolved today for Connected and Autonomous vehicles which have no less than 50 or so ECUs along with the complexities of sensor data and complex wiring.

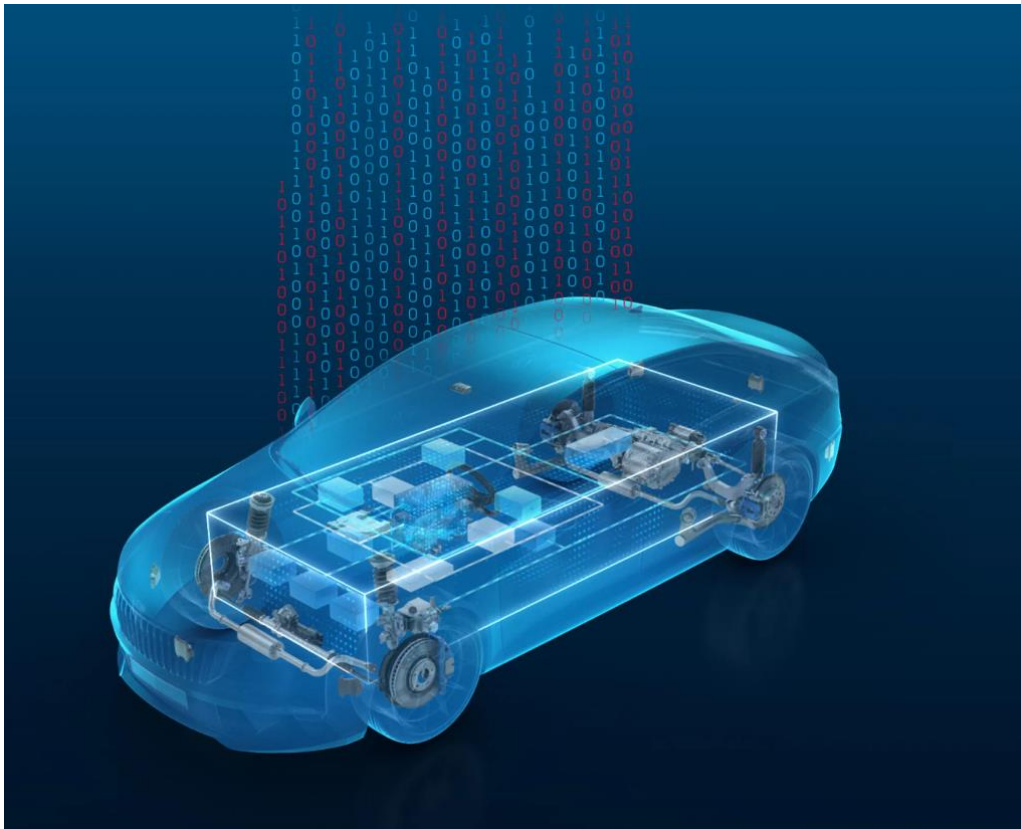


Image Source: <https://ee.cdnartwhere.eu/wp-content/>

# Classical Diagnostics

Classical diagnostics revolves a lot around powertrain functionalities. This focuses majorly on three modules: engine, after-treatment, and transmission. As the names suggest, the control unit handling the engine would definitely be the largest ECU with the following functionalities:

## Fuel Injection Control

The ECU determines the amount of fuel injected into the engine cylinders based on various sensor inputs like Engine speed (RPM), Airflow (measured by the Mass Air Flow sensor), Throttle position, and Engine temperature. By precisely controlling the fuel injection, the ECU ensures an optimal air-fuel mixture for efficient combustion.

## Ignition Timing Control

The ECU determines the exact moment to ignite the fuel-air mixture in each cylinder based on engine speed and other factors. Precise ignition timing ensures smooth engine operation, maximizes power output, and minimizes emissions.

## Engine Air Management

The ECU controls various components that regulate the amount of air entering the engine, such as Intake manifold valves, and Throttle body. By managing airflow, the ECU optimizes engine performance across different operating conditions.

## Engine Monitoring and Diagnostics

The ECU continuously monitors various engine parameters through sensors like Oxygen sensors (to measure exhaust gas composition), Knock sensors (to detect abnormal combustion), and Coolant temperature sensors.

If the ECU detects any issues or malfunctions, it can take corrective actions, such as adjusting fuel injection or ignition timing, or even illuminating a warning light on the dashboard.

## Emission Control

The ECU plays a crucial role in ensuring the car meets emission regulations. It controls components like the catalytic converter and EGR (Exhaust Gas Recirculation) valve to minimize harmful emissions.

## Additional Functionalities

In modern vehicles, the ECU may also control other aspects related to engine operation, such as Idle speed control, Engine cooling fan operation, and Engine braking.

After-treatment deals with the following:

## Catalyst System Management

This majorly focuses on catalytic converters. It monitors the temperature of the catalyst using sensors and adjusts various engine parameters (like fuel injection) to maintain the optimal temperature range for efficient pollutant conversion. Some ECUs may also control additional features like catalyst regeneration cycles, which burn off accumulated soot particles in certain types of filters.

## Emission Control Loop Management

The after-treatment ECU works in conjunction with the Engine ECU to form a closed-loop emission control system. It monitors the exhaust gas composition using sensors like oxygen sensors located before and after the catalytic converter. Based on this data, the after-treatment ECU sends feedback to the Engine ECU, which can then adjust fuel injection, ignition timing, or other parameters to optimize the air-fuel mixture and minimize pollutants in the exhaust.

## System Diagnostics and Monitoring

The System Diagnostics and Monitoring checks for issues like excessive exhaust gas backpressure (indicating potential clogging in the system), sensor malfunctions, and catalyst efficiency degradation.

If the ECU detects a problem, it can illuminate a warning light on the dashboard and potentially implement limp mode (reduced engine power) to protect the engine and prevent further damage. This is made possible through the Instrument Cluster Panel utilizing the standard of J1939.

## Communication with Other Systems

The Aftertreatment ECU may communicate with other vehicle control units, such as the Engine ECU and Diagnostic Trouble Code (DTC) system. This allows for coordinated operation and efficient troubleshooting of emission-related issues.

Transmission deals with the following:

## Gear Selection and Shifting

This gets inputs from sensors like engine speed, throttle position, vehicle speed, engine torque, and transmission fluid temperature. Based on these inputs and pre-programmed shift maps, the TCU determines the optimal gear for the current driving conditions. It then controls various actuators, such as solenoids and hydraulic valves, to smoothly engage the chosen gear.

## Shift Optimization

This has objectives like fuel efficiency, performance, and smoothness.

## Engine and Transmission Coordination

The transmission system communicates with the Engine Control Unit to ensure smooth coordination between the engine operation and gear selection. For example, the TCU requests to adjust engine torque during gear changes.

## Transmission Protection

The TCU monitors various parameters to protect the transmission from damage. If it detects excessive engine RPM, high transmission fluid temperature, or other potential issues, it can limit the engine power, prevent upshifts to higher gears, and engage a limp mode, allowing the vehicle to drive at a limited speed to reach a safe location.

## Diagnostic and Self-learning

The TCU can diagnose potential transmission problems by analyzing sensor data and identifying any irregularities. In some advanced systems, the TCU may also have self-learning capabilities. It can adapt shift patterns based on driving habits and changing conditions to optimize performance and efficiency over time.

# Autosar

Classic Autosar plays an important role when discussing classical ECUs. It has an adaptive counterpart to it. We can discuss more of this in the HPC (High-Performance Computing) section.

## Autosar Layers

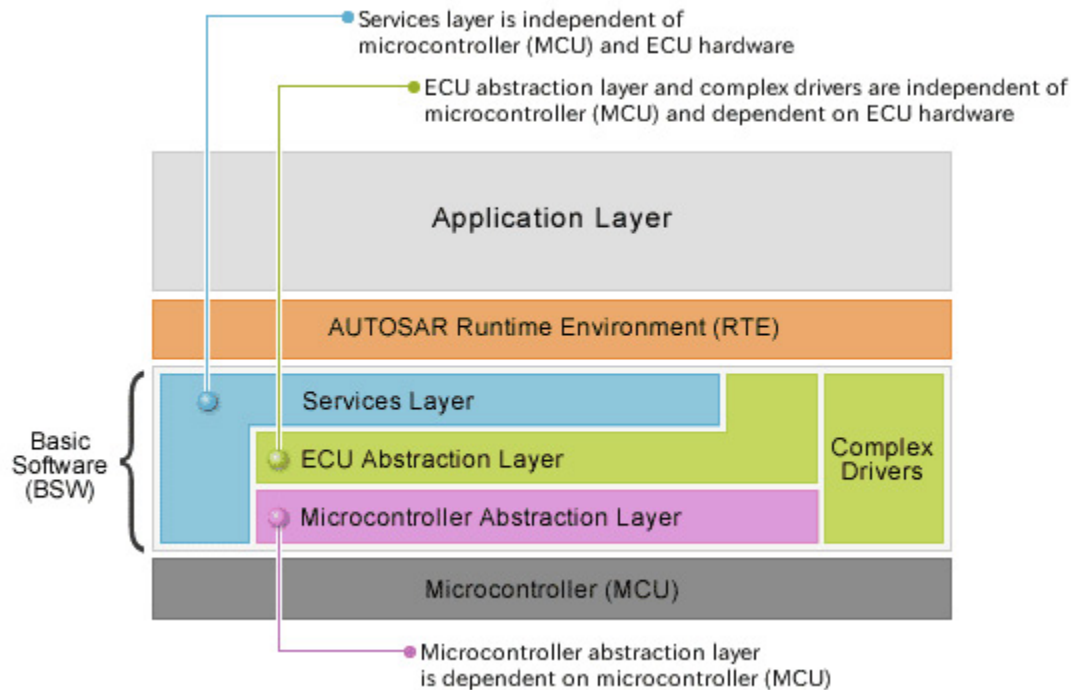


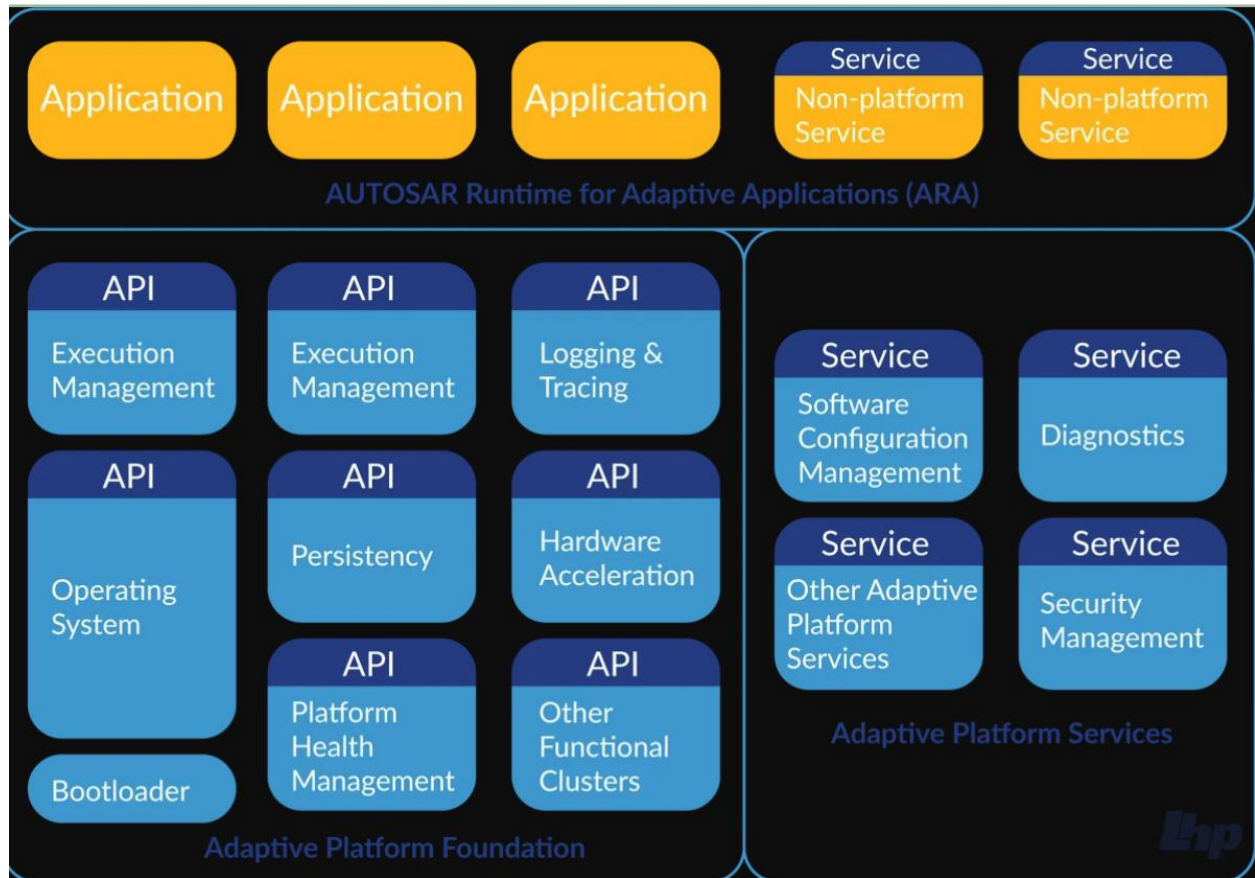
Image Source: <https://www.godaddy.com/resources/in/web-pro-in/an-introduction-to-autosar-layered-architecture>

## High-Performance Computing Diagnostics

### Adaptive Autosar

This comprises a lot of functionality from Autosar combined with additional functionalities like OFR (On The Fly Reprogramming) sequencing which helps in faster flashing and diagnostics necessary for HPCs.

## Adaptive Autosar Layers



Source: <https://www.lhpes.com/blog/what-is-adaptive-autosar>

One can see the variations in Classic and Adaptive Autosar from the above figures. The major difference is the usage of APIs for adaptive to OS and the flexibility to interact with the ECU without a rigid structure as in Classic Autosar.

## SOVD (Service Oriented Vehicle Diagnostics)

The way we diagnose, and fix cars is undergoing a significant shift. Traditional, or classical, automotive diagnostics are becoming limiting as vehicles become more complex and interconnected. This is where SOVD steps in, offering a more efficient and comprehensive approach to vehicles.





*Image source: Gemini generated image showing a Society of Vehicle Engineers (SAE) On-Board Diagnostics (OBD) standard connector.*

#### The Limitations of Classical Diagnostics:

- Classical diagnostics treat the truck/car as a collection of independent domains (engine, brakes, etc.) with dedicated ECUs (Electronic Control Units). Troubleshooting problems can be time-consuming as issues might span multiple domains, requiring specialized tools for each.
- Diagnostic tools often communicate with individual ECUs in a proprietary way. This makes it difficult to get a holistic view of the vehicle's health and limits the ability to update software across multiple ECUs efficiently.
- Static Diagnostics: Classical approaches rely on pre-programmed diagnostic procedures. These may not be effective for identifying problems caused by interactions between different systems in modern vehicles.
- Data Overload: With more sensors and data being generated, traditional systems can struggle to analyze and interpret this information effectively, potentially leading to missed problems.

SOVD offers a new paradigm for truck diagnostics by:

- **Standardization and Interoperability:** SOVD promotes standardized communication protocols and interfaces between ECUs and diagnostic tools. This allows technicians to use a single tool to access data from various parts of the vehicle, regardless of the manufacturer or ECU type.
- **Holistic View:** SOVD provides a more comprehensive view of the vehicle's health. Data from various sensors and systems can be integrated and analyzed to pinpoint the root cause of problems more efficiently.
- **Dynamic Diagnostics:** SOVD enables dynamic diagnostics, where the system adapts its diagnostic procedures based on the real-time data it receives. This allows for a more precise and efficient troubleshooting process.
- **Software Updates:** SOVD facilitates easier and more frequent software updates across multiple ECUs within a vehicle. This can address bugs, improve performance, and unlock new features.
- **Remote Diagnostics:** SOVD paves the way for remote diagnostics, where technicians can access vehicle data remotely to identify and potentially fix problems without requiring a physical visit to the workshop.

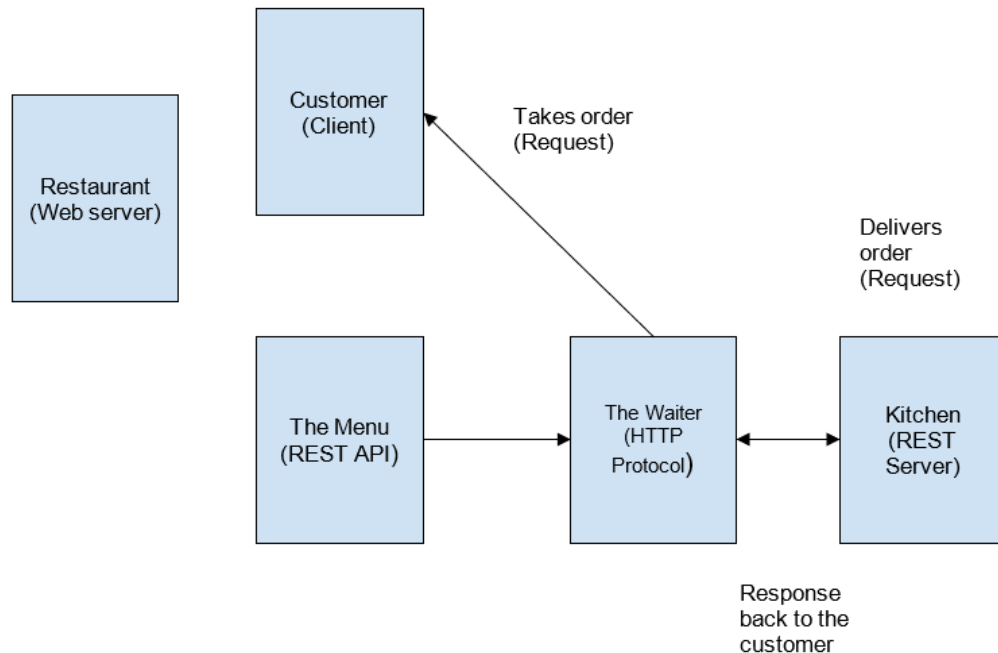
Benefits of SOVD for the Automotive Industry:

- **Reduced Downtime:** Faster and more accurate diagnostics lead to quicker repairs and less time spent troubleshooting.
- **Improved Repair Efficiency:** Technicians can spend less time deciphering complex systems and more time fixing the actual problem, potentially lowering repair costs.
- **Enhanced System Transparency:** SOVD provides a more comprehensive understanding of a vehicle's health, allowing for proactive maintenance and preventing potential issues.
- **Future-Proofing Technology:** SOVD's flexible architecture can adapt to the evolving needs of increasingly complex and software-driven vehicles.

Understanding the protocol:

- **REST(Representational State Transfer Application Programming Interface) API:** Defines the overall structure and functionalities offered by the web service.
- **HTTP((Hypertext Transfer Protocol)):** Provides the communication protocol for sending requests and receiving responses. Think of it as the language used to interact with the API.





## The Road Ahead: A Future of Connected Car Care

SOVD represents a significant step forward for automotive diagnostics. As technology advances, we can expect further developments in this field, such as:

- **Development of Zonal-Specific Diagnostic Tools:** Diagnostic tools will be designed to leverage the zonal architecture of future vehicles, simplifying diagnostics within specific zones.
- **Integration with Cloud-Based Platforms:** Diagnostic data could be uploaded to secure cloud platforms for real-time analysis and remote troubleshooting by experts.
- **Predictive Maintenance:** Advanced data analytics will enable predictive maintenance, where potential problems can be identified and addressed before they cause a breakdown.

## Technologies to Reduce the Complexities and Data Handling

Middleware diagnostics can be a complex and data-intensive process. Here are some technologies that can help reduce these complexities and improve data handling:

### 1. Service-Oriented Architecture (SOA) and Microservices:

- **Reduced Complexity:** By decomposing middleware functionality into smaller, independent microservices, troubleshooting becomes more targeted and easier to manage.

- **Data Isolation:** Data specific to each microservice can be isolated, simplifying analysis and pinpointing the source of issues within the middleware.

## 2. Standardized Logging and Monitoring Tools:

- **Centralized Logging:** Tools like ELK Stack (Elasticsearch, Logstash, Kibana) offer centralized logging platforms for collecting and analyzing data from all middleware components. This helps identify patterns and anomalies.
- **Real-time Monitoring:** Utilizing tools like Prometheus for real-time monitoring of key performance indicators (KPIs) allows for proactive identification of potential problems before they escalate.

## 3. Artificial Intelligence (AI) and Machine Learning (ML):

- **Anomaly Detection:** AI algorithms can analyze log data and identify abnormal patterns that might indicate potential issues within the middleware.
- **Predictive Maintenance:** Machine learning models can be trained on historical data to predict potential failures and enable proactive maintenance, reducing downtime.

## 4. Containerization and Orchestration:

- **Standardization and Isolation:** Containerization technologies like Docker provide a standardized environment for running microservices, simplifying deployment and troubleshooting.
- **Automated Scaling:** Container orchestration tools like Kubernetes can automatically scale resources based on demand, optimizing performance, and reducing data processing overhead.

## 5. API Management Tools:

- **Centralized Management:** API management platforms provide a central point for managing APIs used within the middleware, simplifying monitoring and access control.
- **Data Visibility:** These tools can offer insights into API usage patterns and performance, helping identify bottlenecks and optimize data handling.

## Additional Considerations:

- **Cloud-Based Solutions:** Utilizing cloud platforms can offer scalability and access to advanced analytics tools for managing and analyzing middleware data.
- **Open-Source Tools:** Many open-source options within each of these technology areas can provide cost-effective solutions for reducing complexity and improving data handling.

By implementing a combination of these technologies, developers, and engineers can streamline middleware diagnostics, reduce the burden of manual data analysis, and gain valuable insights into the health and performance of their middleware systems.

## Summary and Future Scope

This report explored the evolution of middleware diagnostics in vehicles, highlighting the limitations of classical methods and the potential of Service-Oriented Vehicle Diagnostics (SOVD) for the future.

### Classical Diagnostics: A Bygone Era?

Traditional diagnostics focused on individual ECUs (Electronic Control Units) handling specific functions like engines or transmissions.



*Image source: <https://www.techsat.com/automotive-middleware-for-development-new>*

Troubleshooting involved specialized tools and was time-consuming, especially for complex issues spanning multiple domains. Data overload from modern vehicles further strains these methods.

SOVD represents a significant leap forward for automotive diagnostics. By embracing this future-proof technology, the industry can ensure efficient, reliable, and cost-effective vehicle maintenance.