TRIGO
Global Quality Solutions

HOW AI-POWERED SOLUTIONS ARE TRANSFORMING VEHICLE ELECTRONIC CONTROL UNITS AND INTERIOR PARTS QUALITY INSPECTION

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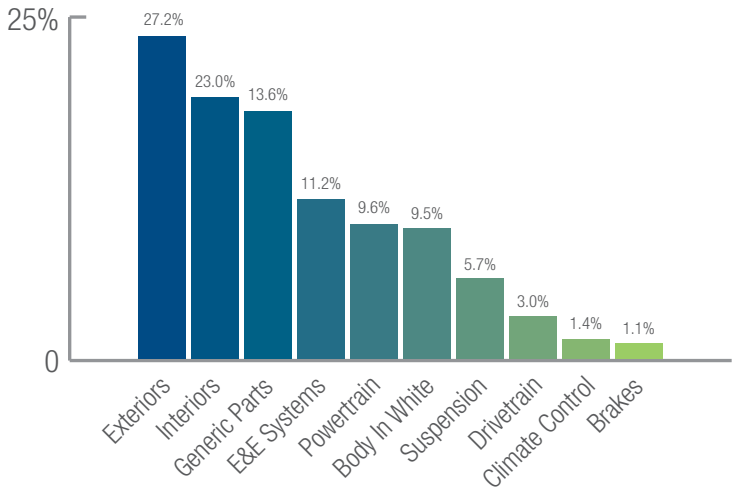
Introduction: Analysis of 17 Global OEM Plants Revealed Exterior and Interior Components Drive 50% of Quality Containment Costs

Vehicle launches represent a critical project phase where operational quality management faces its greatest challenges. Analysis of supplier quality data reveals a persistent pattern: long-established interior and exterior vehicle components manufactured by suppliers continue to dominate containment actions at OEM assembly plants despite advancing manufacturing technologies.

Drawing from TRIGO's global quality management database, which tracks real-time containment services, this analysis focused on data from the second quarter of 2024, coming **from 17 OEM assembly plants in 7 countries**, encompassing quality containment actions across 229 unique suppliers and 57 different component categories. The findings demonstrate that **the components most subject to quality issues are exterior components (27.2%) followed by interior parts (23.0%) and generic joining components parts (13.6%)**.

Breakdown Of Quality Issues Per Vehicle System



Analysis of quality data reveals three distinct tiers of vehicle system challenges:

- **Major Occurrence Group** (>17%): Led by **exterior components, interior assemblies, and generic joining components**, representing the highest frequency of quality issues.
- **Moderate Occurrence Group** (9-12%): Contains **electrical and electronic systems**, powertrain components, and body-in-white structures, showing intermediate frequency of quality challenges.
- **Minor Occurrence Group** (<6%): Comprises **suspension and steering systems, drivetrain components, climate control units, and braking systems**, displaying lower but notable quality incidents.

Based on this study, this white paper explores three critical aspects of modern automotive quality management:

- First, we examine the **growing challenges posed by electronic and electrical systems in terms of quality management**, with particular focus on Electronic Control Unit software updates and their impact on quality management costs.
- Then, we analyze the **persistent quality challenges in interior components**, which despite decades of manufacturing experience, remain a significant source of quality issues.
- Finally, we demonstrate **how AI-powered inspection solutions are revolutionizing quality control processes**, particularly for interior components, offering new possibilities for enhanced defect detection and quality assurance.

This analysis not only highlights current challenges but also provides insights into how emerging technologies and methodologies are reshaping quality management in the automotive industry.

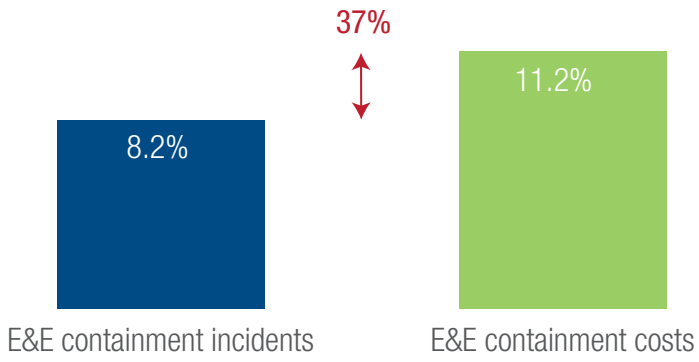
1. THE GROWING CHALLENGE OF ELECTRONIC & ELECTRICAL SYSTEMS IN QUALITY

A. Current state of Electronic & Electrical Systems (E&E)

Further analysis of the data reveals an important insight regarding Electric & Electronic Systems (E&E): while they represent 11.2% of total containment costs, they account for 8.2% of the total number of incidents. This higher containment cost-per-incident ratio can be attributed to the complexity of resolving electronic issues, particularly the frequent need for re-flashing operations. Unlike mechanical components that may require simple sorting or rework, electronic systems often demand specialized equipment, more trained personnel, and time-intensive software updates to address quality concerns.

As vehicles continue to incorporate more complex electronic systems, this trend of increasing Electric & Electronic related containment actions and their associated costs is expected to become even more pronounced.

E&E containment incidents vs. containment costs



B. Electronic Control Units (ECUs): Rising demand during new vehicle launches of the ECU's Software updates

a) Overview of modern vehicle ECUs

Given the unique challenges posed by E&E systems, particularly in terms of specialized equipment and expertise requirements, understanding overall E&E architecture and Electronic Control Units (ECUs) for optimizing containment actions is essential for reducing overall quality management costs, as these components are becoming the backbone of modern vehicle electronics and present distinct quality challenges.

Today's vehicles may contain around 50 ECUs, controlling essential functions such as engine and power steering, comfort features like power windows, seats, and HVAC (Heating, Ventilating and Air Conditioning), as well as security systems including door locks and keyless entry. Additionally, ECUs manage passive safety features such as airbags and basic active safety features like automatic emergency braking. With the increasing sophistication of modern vehicles, the quality of ECUs significantly influences safety, performance, and customer satisfaction.

Modern Electronic Control Units integrate advanced software algorithms with complex hardware platforms. Ensuring hardware-software integration presents significant challenges, primarily due to the **diverse ecosystem of component suppliers, multiple software versions, and varying system configurations.** This complexity has driven automotive manufacturers to pursue a strategy of ECU consolidation, aiming to simplify vehicle development by reducing the total number of control units per vehicle.

b) The 4 critical Electonic Control Units requiring re-flashing

At TRIGO, we have identified the **top four car control units frequently requiring re-flashing** at the OEM production plant:

1. **Engine Control Unit:** This unit functions as the engine's brain, continuously analyzing data from multiple sensors to optimize engine performance, fuel efficiency, and emissions control. It manages critical parameters including fuel injection timing, air-fuel mixture, ignition timing, and variable valve timing, adapting these in real-time to various driving conditions.

2. **Transmission Control Unit:** This unit oversees the vehicle's transmission, ensuring that gear shifts occur at appropriate times for optimal performance and efficiency. It utilizes algorithms to determine optimal shift points based on factors such as vehicle speed, engine load, throttle position, and driving mode. Modern TCUs also integrate adaptive learning capabilities to adjust shift patterns according to driving style and conditions.

3. **Body Control Module:** This module manages various vehicle comfort and convenience functions, including interior and exterior lighting, power windows, central locking, climate control, and windshield wipers. As vehicles become more sophisticated, BCMs increasingly handle complex features like keyless entry systems and automatic climate zone control.

4. **Infotainment Unit:** This unit controls the vehicle's entertainment and information systems, managing functions such as audio systems, navigation, Bluetooth connectivity, smartphone integration, and various multimedia features. With the growing importance of connected car features, these units frequently require updates to maintain compatibility with new devices and services, as well as to implement security patches and feature enhancements.

C. Evolving ECU complexity intensifies re-flashing operations having significant cost implications

a) Cost implications & key operational challenges

A common action following a quality incident involving ECUs is re-flashing both the stock at the OEM and the in-transit components. This process is complex for several reasons:

- **Long Process Times:** Re-flashing a component can take several minutes, extending the overall process time.
- **Equipment Shortages:** There is often insufficient equipment to meet the required takt time for the assembly line.
- **Inadequate Equipment for Continuous Use:** The re-flashing equipment used is typically designed for laboratory testing and validation, not for continuous 24/7 use in a manufacturing environment.
- **Consumable Wear and Tear:** Cables and connectors need frequent replacement after a certain number of cycles to prevent breakage.
- **Human-Error Proof Material Flow and Standard Operational Work (SOW):** Operators need to manage several re-flashing stations simultaneously, including parts with incomplete re-flashing.
- **ESD Protection:** Ensuring a proper Electrostatic Discharge (ESD) Protected Area is essential to avoid damaging parts.

b) Update protocols

Additionally, re-flashing process implementation can vary significantly depending on the communication protocols that need to be implemented:

1. **Open protocols** are predominantly used for non-critical components, enabling straightforward software updates with standard diagnostic tools. These protocols typically operate over standard automotive networks like CAN bus or Ethernet and follow standardized diagnostic specifications (ISO 14229/15765).

2. **Protected protocols requiring OEM authentication** represent a middle-ground approach. These systems implement security mechanisms that are implemented by the OEMs by employing proprietary security access algorithms and session keys to prevent unauthorized modifications.

3. **Supplier-proprietary protocols** represent the most restricted category, where software updates can only be executed by the original component supplier. These protocols often incorporate advanced security features. While this approach provides maximum control over critical system modifications and intellectual property protection, it can significantly impact re-flashing workflows and increase re-flashing costs. Suppliers employ these proprietary protocols to implement tiered feature access, allowing them to disable or enable specific functionalities based on pricing models.

4. **Over-The-Air (OTA) updates** represent an emerging solution to address ECU re-flashing challenges in modern vehicles. Unlike traditional re-flashing methods that require direct access to the vehicle, OTA technology enables manufacturers to remotely deploy software updates to vehicle ECUs through wireless connectivity. This capability significantly reduces operational costs, and the logistics complexity associated with traditional re-flashing procedures at dealerships or manufacturing sites. OTA systems must be designed with fail-safe mechanisms to prevent incomplete or corrupted updates that could compromise vehicle functionality. Despite these challenges, the automotive industry is increasingly adopting OTA capabilities as a strategic solution to streamline ECU software management and enhance vehicle maintainability throughout its lifecycle.

At TRIGO, we have developed specific service solutions to optimize the cost of traditional re-flashing operations, which can easily amount to tens of thousands of dollars when performed at the OEM. By addressing the challenges mentioned above, we aim to enhance the efficiency and reliability of ECU re-flashing processes, ensuring better quality control and cost management for both automotive manufacturers and component suppliers.

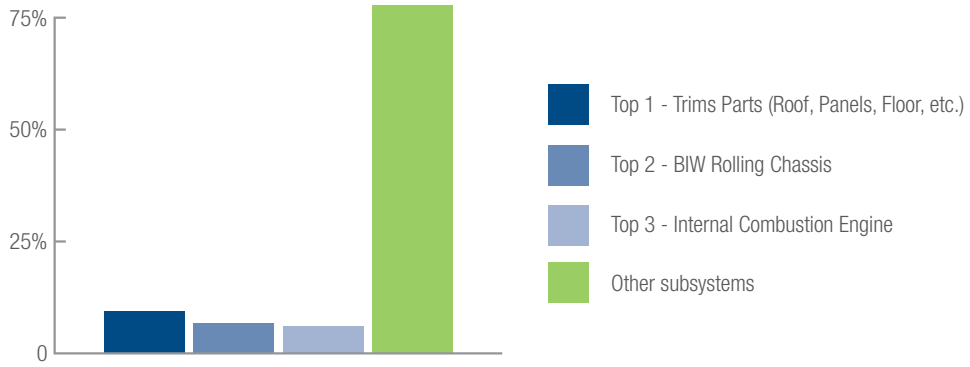
2. PERSISTENT QUALITY CHALLENGES IN INTERIOR COMPONENTS

A. Current state analysis

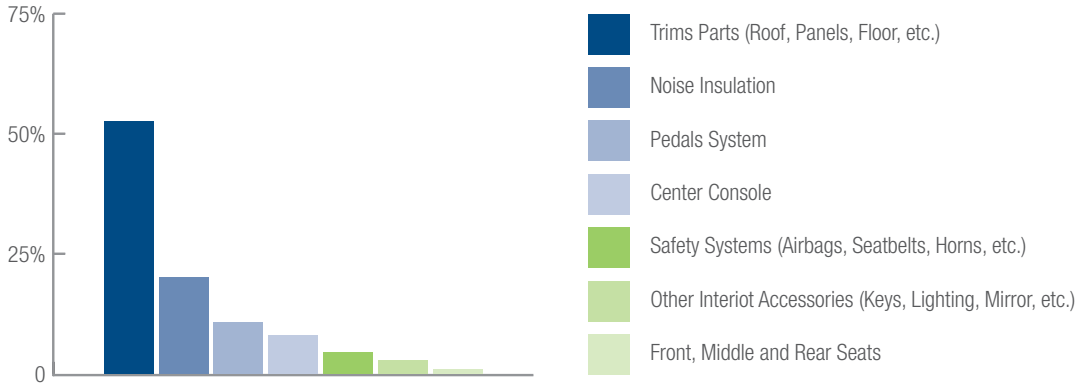
Interior components from suppliers play a vital role in shaping how drivers and passengers experience a vehicle - from perceived quality to safety and practical functionality. TRIGO's research shows these supplier components consistently lead to more containment actions at OEMS than any other vehicle parts throughout the production lifecycle.

Diving deeper into the data, Interior Trim Parts emerge as the most problematic category, responsible for 17.5% of quality issues globally and 52.5% of interior quality issues that require containment actions. This category encompasses roof components, panels, and flooring materials. This incident rate reflects the growing complexity of automotive design and technology, **highlighting the need for suppliers to develop more sophisticated quality control processes** specifically for these interior elements.

Top 3 Subsystems Generating Containment Actions



Quality Incidents Breakdown by Interior Component Type



B. Defect classification

While automakers implement comprehensive quality checks during new model launches, before vehicles reach customers, certain issues can still slip through. This is particularly true for aesthetic defects - while they may not compromise the vehicle's operation, they can significantly impact customer satisfaction and their perception of the vehicle's overall quality.

The defects that TRIGO controls for interior parts can be broken down into these types:

Aesthetic Defects

- Surface imperfections (scratches, dents, marks)
- Color and texture inconsistencies across components
- Visible material imperfections in fabrics, leathers, or plastics
- Uneven fading or discoloration of materials
- Gaps and misalignments between panels

Assembly & Fit Issues

- Panel separation or delamination
- Trim detachment or loosening
- Material warping due to environmental exposure
- Component deformation under temperature variations
- Premature material degradation in high-stress areas

Functional Defects

- Malfunction of movable components (storage compartments, cup holders)
- Improper operation of adjustable elements
- Restricted movement of sliding or folding parts
- Compromised safety feature performance
- Inadequate component retention

Sensory Concerns

- Noise generation (squeaks, rattles, vibrations)
- Material off-gassing and odor emissions
- Irregular surface texture
- Inconsistent tactile feedback
- Uneven illumination in lighting components

3. THE FUTURE OF QUALITY INSPECTION: THE NECESSARY AI-POWERED INSPECTION TO ELEVATE AUTOMOTIVE INTERIOR QUALITY STANDARDS

A. Current limitations and needs

The automotive interior components industry still faces challenges in maintaining consistent quality control across high-volume production environments. Traditional automated optical inspection methods often struggle with complex geometries, subtle defects, and the need for comprehensive multi-angle analysis. This has created a pressing need for more sophisticated inspection solutions that can deliver both precision and scalability.

AI-powered visual inspection systems have emerged as a transformative solution, offering several key advantages over conventional methods:

- Advanced pattern recognition capabilities that can adapt to various component types
- Real-time processing of complex surface characteristics
- Consistent performance across large production volumes
- Reduced dependency on human operator variability
- Ability to detect subtle defects that might escape traditional inspection methods

B. AI-Powered Solutions

TRIGO, through its subsidiary Scortex, has developed a cutting-edge AI-based inspection solution specifically designed for these challenges. The system demonstrates the practical application of refined deep learning algorithms in two key areas:

1. Complex Surface Defect Detection:
    - Automatic identification of surface irregularities through high-resolution imaging
    - Heat map visualization of detected anomalies, enabling precise defect localization
    - Real-time analysis of critical areas, as shown in the inspection of metal components where subtle surface variations are caught
2. Multi-Point Inspection:
    - Simultaneous evaluation of multiple critical zones
    - Advanced pattern recognition for complex geometries
    - Comprehensive component analysis from multiple viewing angles (up to 4 perspectives)

This integration of advanced visual inspection technology represents TRIGO's commitment to developing innovative quality control solutions that address the evolving challenges in automotive component manufacturing, while maintaining high throughput rates and consistent quality standards.

CONCLUSION: OUR PRACTICAL TAKEAWAYS TO IMPROVE THE EFFICIENCY AND QUALITY OF YOUR SUPPLY CHAIN

1. **Prioritize interior & exterior components supplier oversight:**

    - These components collectively account for 40.1% of containment costs.
    - Focused supplier engagement and enhanced quality management are essential to mitigate recurring issues in these categories.

2. **Adopt AI-Driven inspection solutions for interior parts quality control:**

    - Deploy AI-powered visual inspection, like TRIGO's Spark solution designed by Scortex, to improve inspection accuracy, reduce human dependency, and scale quality management for complex geometries and subtle defects.
    - Create data-driven feedback loops to continuously improve detection accuracy

3. **Plan for Electronic & Electrical Systems containment actions:**

    - E&E systems show an unequal & rising cost impact due to more complex resolutions.
    - Address the increasing cost of containment for E&E systems by investing in specialized diagnostic tools and training to streamline re-flashing operations.
    - Partner with third-party service providers for scalable containment operations to reduce long-term costs.

Ricard Lou currently is Group Data Solutions Director at TRIGO Group. Joining TRIGO in 2011, he has been instrumental in the company's development, serving as the Director of Operations in Spain & Portugal, and subsequently as Group Project Management Officer. Having completed a graduate degree in industrial engineering in Spain (Universitat Politècnica de Catalunya), France (CentraleSupelec), and Germany (Universität Stuttgart) and a master degree in project management (EAE Business School), he has over 15 years of experience in the automotive industry. He joined the Group's Innovation & Strategic Ventures team in 2022 focusing on advancing TRIGO's proficiency in data applications.