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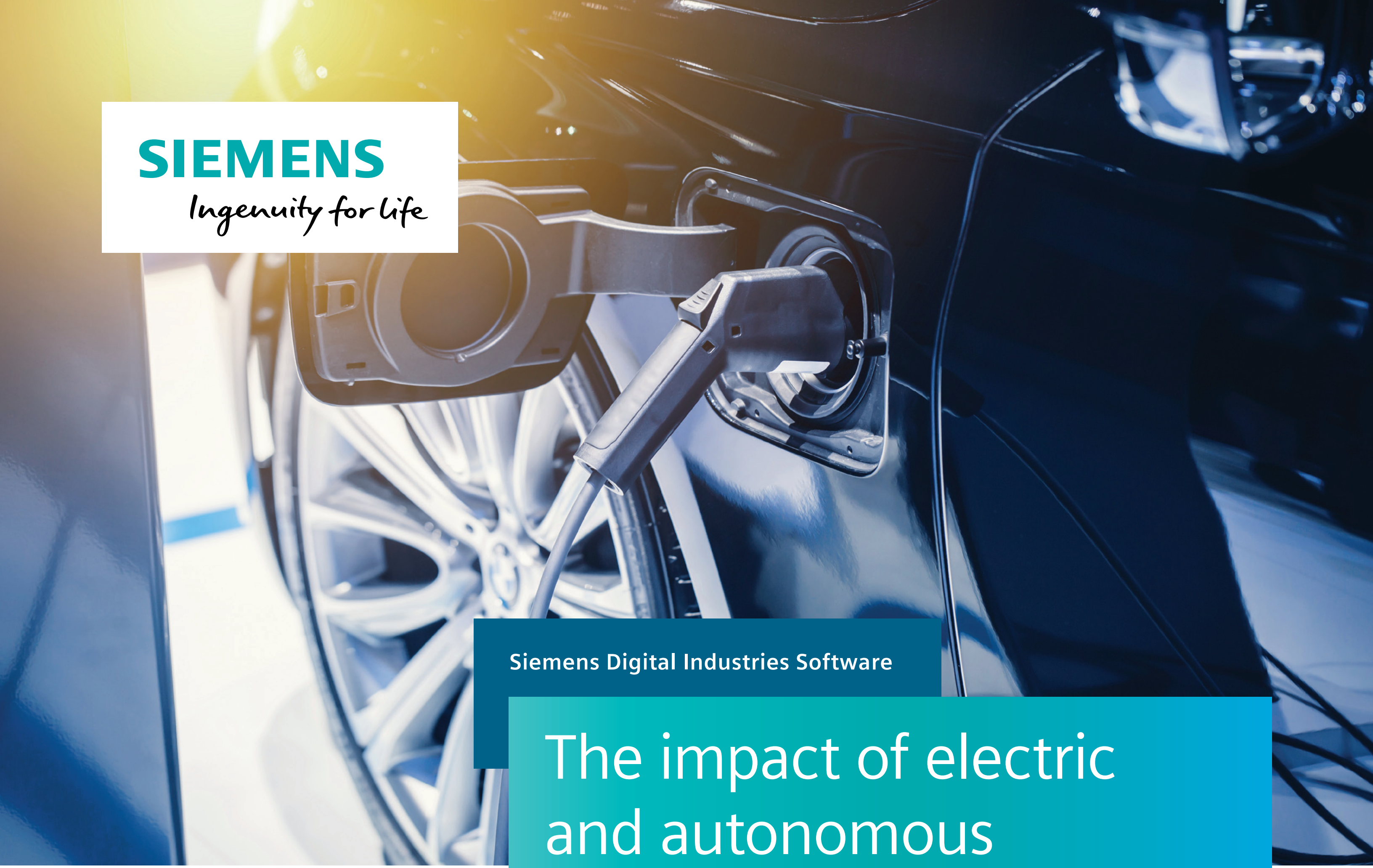

Siemens Digital Industries Software

The impact of electric and autonomous vehicles on aftersales service and maintenance

Electrical systems

Executive summary

The growing electrification and automation of vehicles will have extensive effects on vehicle servicing and maintenance. As automakers integrate more sophisticated electrical and electronic systems, the challenges of vehicle servicing will change. Advanced electrical systems engineering solutions can automate the generation of accurate and interactive service documentation, equipping service technicians with the tools they need to overcome the challenges of maintaining these advanced vehicles.

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Introduction

Automotive industry trends towards electrification and autonomy will have wide-ranging effects in the engineering, manufacturing and servicing of vehicles. The first significant impact of electric and autonomous vehicles on the after sales and service environment derives from the transition from complex mechanical systems to electrical systems in vehicles. Vehicles today are largely mechanical machines, due to the persistence of the internal combustion engine. Yet, mechanical means of vehicle propulsion will soon be outdated as market demands for electric powertrains continues to increase. Internal combustion engines will be replaced by electric motors that are relatively less complex and require much less maintenance (figure 1).

The second impact comes courtesy of the sheer increase in complexity of the electrical and electronic systems in EVs, and especially AVs. A level-five autonomous vehicle will use a network of forty or more advanced sensors to perceive the driving environment. This network will link LiDAR, radar, camera and other sensors to detect key features of the vehicle's environment such as road lines, traffic signs and signals, other vehicles and pedestrians. The sensor network must connect to a network of ECUs that will process the incoming data and distribute instructions around the vehicle. The wiring harness enables all of these data transmissions and supplies power to the sensors and ECUs, making it both very important and increasingly complex.

Electric and autonomous vehicles bring unique and intricate challenges to the service environment that may require special training or bespoke processes to manage. Service technicians will need new techniques and expertise to diagnose and repair electric and autonomous vehicles effectively and, most of all, safely.

Figure 1: Electric vehicles will come to dominate the market.

EV service challenges

Electric powertrains require extremely high-voltage wiring to carry power from the batteries to the electric motors and other critical systems. As a result, EVs require additional safety precautions to protect the service technicians performing maintenance (figure 2). Vehicle design and workshop procedures both must adapt to meet these heightened safety needs.

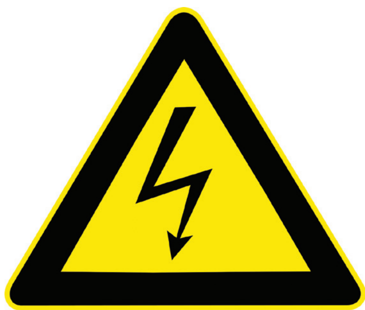

Figure 2: EVs require additional safety procedures such as signage, separated work bays and personal protective equipment (PPE).

EV manufacturers have adopted a "safety by design" approach by integrating safety mechanisms into the design of the high-voltage wiring and systems. This is achieved in several ways:

- The inclusion of a high-voltage interlock loop, which is a wired connection between all the high-voltage components on the vehicle. In the event that a technician disconnects a high-voltage component without safely shutting the vehicle down, the high-voltage interlock loop breaks power from the system and disconnects the battery, making it safe for the technician.
- Short circuit monitoring to constantly measure resistance between the high-voltage lines and the ground to make sure there is no drop in resistance. If a drop occurs, the system will shut down to prevent damage or injury.
- Potential equalization lines that connect all high-voltage components to the same potential. These lines prevent the technician from becoming the path to earth while working on a faulty high-voltage component.

Vehicle design, however, is not the only determiner of technician safety. Workshop organization and procedures must adapt to mitigate the potential dangers of servicing high-voltage systems. As vehicles come into the workshop, high-voltage vehicles need to be separated into dedicated bays for diagnosis and service. Only technicians with appropriate training should be allowed to enter this service bay. Proper signage and a physical barrier, such as a fence, are necessary to ensure that all employees know which vehicles have high-voltage components, and thus which service bays to avoid. Signage can help communicate the state of a vehicle to all technicians clearly and concisely.

In addition, the separation of high-voltage vehicles is an important precaution for batteries in critical condition. Critical batteries may be leaking dangerous chemicals, or may undergo thermal runaway. Thermal runaway is a dangerous reaction involving the liquid electrolyte inside battery cells. A short circuit in the battery can combust the electrolyte causing pressure inside the cell to increase until it ruptures. A ruptured cell can exceed temperatures of 1,800°F and quickly propagate to other cells. Both events pose serious threats to the health and safety of nearby technicians, and require special training for proper management.

Before normal maintenance or repairs to the high-voltage system, technicians must shut the system down safely. This requires special insulated tools to protect technicians from electric currents. High-voltage technicians also need personal protective equipment (gloves, eye protection, facemasks and coveralls) while working with batteries and other components. Furthermore, special containment is needed to safely store and ship critical batteries for proper disposal or recycling. Even with appropriate containers, many freight carriers will not ship high-voltage batteries due to cost.

These safety improvements are essential for servicing high-voltage vehicle systems, but ensuring that technicians have appropriate training is equally as important. Training for high-voltage vehicles or high-voltage systems in electric vehicles is crucial due to the unique requirements and precautions of these systems in a service environment. A service environment encompasses many different people with different roles that work in and around vehicles under service. Therefore, different levels of training are appropriate for different employees (figure 3).

The first level of training focuses on awareness. Everybody in the dealership or service shop needs to be aware that the business will be servicing electric vehicles. The administrator, service advisor, workshop manager and even people that don't perform services such as the janitor or valet all need a level of awareness training. This training covers basic safety procedures such as warning signs on EVs under service, and only takes a few hours to complete.

The next level is high-voltage technician training. High-voltage technician training teaches the shutdown and startup procedures for high-voltage vehicles. Technicians must properly shut down high-voltage vehicles before work can begin safely, and start them back up before returning the vehicle to the customer. This process is initiated with every high-voltage vehicle that comes into the shop, whether repairs are needed on the high-voltage system or on something as simple as a wiper blade motor. High-voltage cabling may run in close proximity to any number of systems in the vehicle, making it vulnerable to damage during repairs. The involved technicians must also document this process to ensure that repairs are traceable, and that the vehicle is returned to a safe state before it leaves the shop.

Finally, some technicians need to undergo advanced training to act as the high-voltage expert in a service location, build facility or dealership. This expert is responsible for battery diagnosis, classification, recycling, replacement and, eventually, battery repair. Vehicle batteries can cost tens of thousands of dollars, meaning faulty batteries can quickly increase manufacturer warranty costs, and cost of ownership for the customer. To reduce the cost of faulty batteries, EV manufacturers are examining battery repair strategies to incorporate into these advanced trainings.

High-voltage training is very important, but it requires a significant time and financial investment from a service organization. Trainings take technicians and other employees away from their normal job duties and require investment in materials and trainers. Furthermore, dealerships and shops must train multiple technicians at each of the higher levels of expertise to ensure that work can proceed despite unforeseen circumstances. Periodic re-training is also necessary to update technicians on new procedures or technologies, and to keep skills sharp despite initially low volumes of electric vehicles.

A final benefit of consistent trainings is the establishment of consistent and coordinated processes for accepting and repairing electric vehicles. Service organizations must create processes to ensure the safety of all technicians and employees near the vehicle. For instance, technicians should pay special attention to the condition of the battery during fault diagnosis. If the battery is critical, then technicians should immediately quarantine the vehicle. If not, then the high-voltage system should be shut down

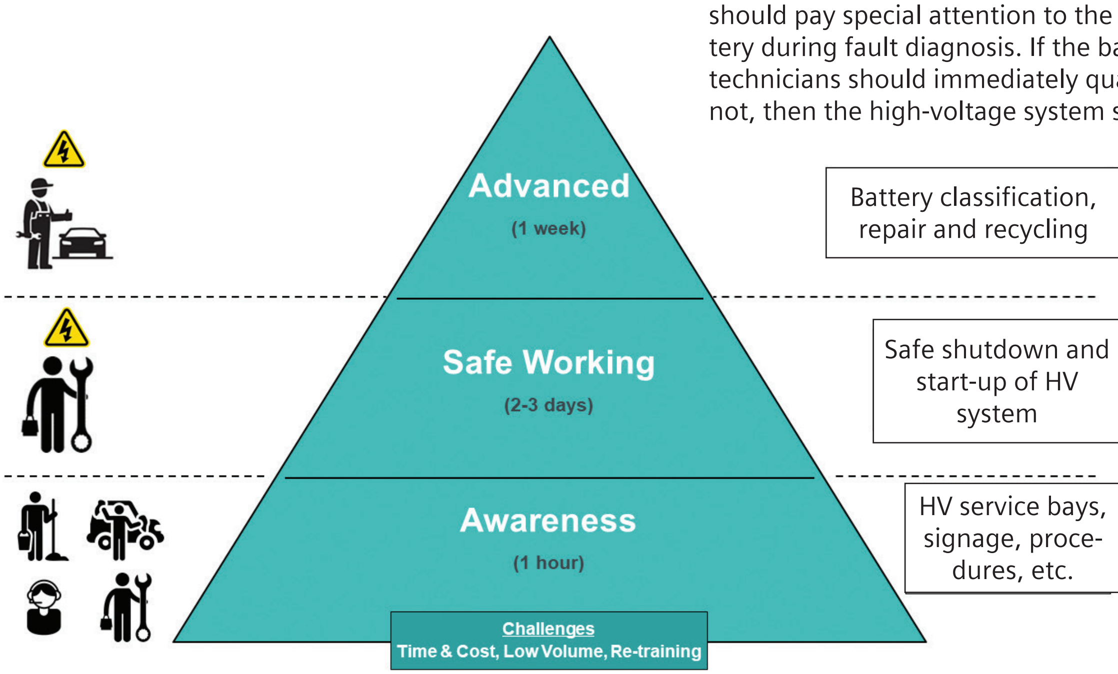

Figure 3: Various levels of training are necessary for the wide range of employees in a service environment. This figure shows indicative durations.

by a high-voltage technician, allowing further diagnosis and repair. Different stages throughout this process require different levels of training, which in turn depends on the location of the fault.

Finally, consistent documentation of the repair process is indispensable. Technicians must keep track of the actions they take and any measurements they record at each stage of the diagnosis and repair process.

Capturing these details in the service documentation ensures traceability of the service process. For example, visual inspection and potential equalization measurements are necessary after replacing a high-voltage component to ensure the component fits correctly and has not introduced additional resistance. The component replacement and the results of the inspection must both be captured in the service documentation.

Servicing autonomous vehicles

The electrical systems in autonomous vehicles will be the most complex automotive systems to date. Autonomous vehicles will come equipped with an array of sensors and computers to perceive and react to the external driving environment. These will include cameras, infrared, radar, ultrasonic and LiDAR sensors as well as powerful computing units and actuators to turn signals into motion. Each system will have redundancies to ensure safe operation in the event of a failure. This means additional wiring and ECUs to manage the redundant systems and deploy them when necessary. The effect of all of this increased complexity is a vast increase in data processing and storage needs, wiring harness complexity and the introduction of new service challenges.

The accurate service and repair of autonomous vehicles, will be central to their continued safe and reliable operation. For technicians, it will be imperative to identify faults accurately and prescribe the correct solution. Service documentation and trainings will be indispensable methods of establishing traceability and guaranteeing the quality of these repairs and maintenance. Parts must be installed, adapted and configured correctly. Then, automatic checks will verify the accuracy of the repair and document that the repair was made. In the case of an accident, this information will be important to demonstrate that the vehicle was serviced in line with OEM recommendations (figure 4).

Due to the complexity of autonomous systems and the heightened need for accuracy, there is a training skills gap between autonomous and human-driven vehicles. Transitioning service technicians from mechanical to electrical services, or to high-voltage, is just the first step in training the autonomous vehicle service workforce. To move to AV service requires a non-linear increase in technician skill. This is because autonomous service technicians will need to inspect and service the network connectivity inside the vehicle. Imagining the service department of the future, Greg Potter from the Equipment and Tool Institute in Michigan says, "The dealership service department will resemble the Genius Bar of an Apple store. Network engineers will work alongside lower-skilled techs who do oil changes and rotate tires."

This will drive a transformation of vocational training programs that exist today. Partnerships between OEMs and colleges will need to be fostered to create technical centers of excellence for autonomous vehicles. These

Figure 4: Successfully tracing service, repair, and maintenance information will only be more important as autonomous vehicles become a reality.

centers will be vital in order to improve the skills of service technicians to meet the demands of autonomous vehicles, which include dozens of interacting subsystems, tens of thousands of signals, millions of lines of software and billions of possible vehicle configurations.

New tools to enhance automotive service

What sort of tools will service organizations need to prepare for the challenges of EV and AV after-sales service and maintenance? Today, software vendors offer highly advanced electrical system and wiring harness engineering tools that span the electrical system lifecycle from definition through production and maintenance. One of the most important features of these tools is their ability to digitize and automate previously manual processes, such as the creation of service manuals and signage.

A class of these new design tools is focused on reducing the time and resources required to create technical documentation. Advanced examples, such as Capital Publisher, are able to reuse data directly from upstream engineering processes. Engineers no longer need to take data from a spreadsheet and manually redraw wiring diagrams. All the necessary data can be imported and automatically laid out into accurate wiring diagrams.

Previously, the technical publications department would have manually pulled the needed data together, laid out the schematics and checked that the wiring data matches the engineering data. Now, engineers can configure the automated generation of electrical documentation (figure 5). The configurable engine consumes design data, 3-D models, location views, diagnostic codes, repair procedures and corporate assets like symbol libraries and graphical styles. Then engineers can mine and link adjacent data, re-partition diagrams, re-style documentation and even export to multiple formats such as PDF, HTML and S1000D. After ensuring that the schematics fit on pages correctly and will be practical in the service environment, the tool can integrate connectivity information automatically.

To maximize the practicality of service documentation, these new tools output a smart, interactive and

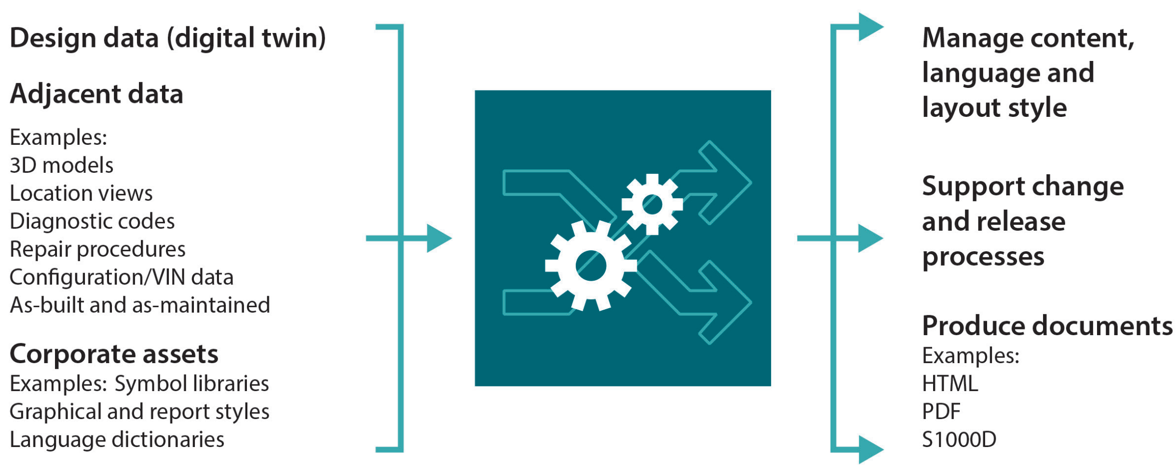

Figure 5: Advanced tools can automatically generate service documentation, removing hours of manual work.

standalone documentation package. This package is extremely portable, and can be hosted from a server or a single laptop. Then, engineers can integrate the documentation into any number of after-sales publications and OEM systems. Of course, it can also remain as a standalone package. Even after the documentation is created, engineers can configure the layout, styling and more. The configuration is intuitive and highly interactive, allowing engineers to create the specific views of a vehicle that are needed.

What's more, the schematics generated by the tool have "click and sprout" functionality that enables users to focus on only the circuit elements that are relevant to a diagnosed issue or repair. The schematic can also link to each different wiring diagram automatically, allowing users to jump between the schematic and wiring diagrams.

The ability of modern design tools to automate the creation of technical documentation has clear benefits for the technical authoring team such as shorter publication cycle times, lower publication creation costs and fewer publication errors. However, the documentation can also be used in house for design reviews and for monitoring changes between harness designs and the service and maintenance technician environment. For design reviews and supplier communications, tools such as Capital Publisher provide richer content that improves comprehension and change identification. Using the documentation, service and maintenance technicians can diagnose faults, repair the vehicle and return it to the customer faster. As a result, the technicians can improve brand image and value, customer retention and customer satisfaction by eliminating repeat repairs.

Stepping through a high-level fault diagnosis process using the smart documentation can help illustrate its value (figure 6). An electric vehicle has been brought into the shop with a defective dome light. Having identified the malfunctioning part, a technician can use the smart documentation to automatically generate a test plan. The test plan provides the technician with step-by-step instructions to locate the source of the fault. Inside each step are links that can supply the technician with additional information related to the part, such as its location in the schematic, connector and pin out views and wiring diagrams.

The first step is to check the battery voltage. Clicking on the link in the first step automatically brings the technician to the wiring schematic. After verifying that the battery voltage is acceptable, the technician moves on to step two, the power distribution unit (PDU). In this case, the technician doesn't know where the PDU is located, but they can retrieve a 2D top view of the vehicle that highlights the relevant part. Having located and verified the supply voltage of the PDU, the next step is to open the box and measure the resistance across a specific fuse. The resistance of this fuse is within acceptable values, so the technician moves on to the next step in the test plan.

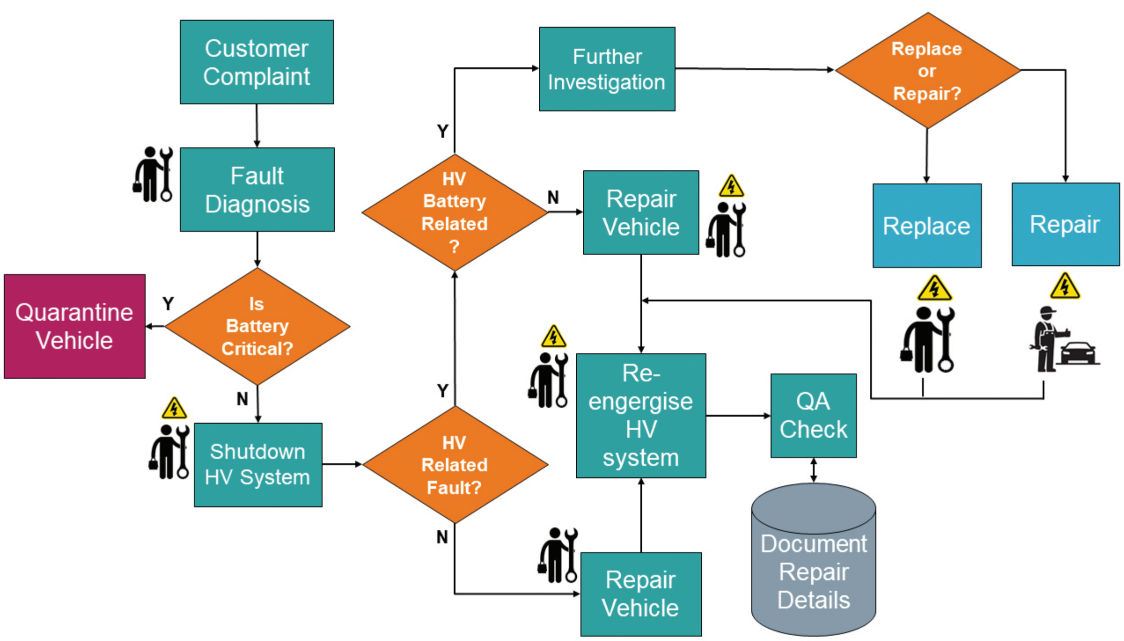

Figure 6: An example of an electric vehicle repair process.

Next, the technician needs to disconnect the inline connector that goes from the PDU to the battery, and check a specific pin on the connector. To find the right pin, the technician can bring up a face view of the connector showing each pin number and check the voltage of the correct pin.

The technician progresses through the test plan, systematically locating and verifying only components that are relevant to the malfunctioning dome light. Eventually, the technician is able to determine that a damaged switch was the source of the fault. The technician replaces the switch and the issue has been resolved.

Maintaining the future of transportation

Smart and interactive service documentation helps to resolve the issues raised by electric and autonomous vehicles in the service environment. By directly using the harness design data, engineers can be sure that the information in the service documentation is completely accurate. This is critical with the complexity of autonomous vehicle systems and the routing constraints of high-voltage wiring. Inaccurate wiring diagrams may lead to safety concerns in the service environment if high-voltage components are not identified properly.

Advanced electrical system solutions can also perform design rule checks to verify the accuracy of the data in the documentation. For example, design rules can ensure that high-voltage wiring is colored orange, communicating to technicians to take additional care when working with such wires. Design rules can also check to make sure that the high-voltage interlock loop, an important safety-by-design feature, is replicated in the service information.

Next, smart documentation helps technicians perform methodical and efficient fault diagnosis. The immense complexity of autonomous vehicle systems would cause significant delays in the service process if technicians were left to navigate them alone. Furthermore, a methodical process further improves safety by making it clear when the high-voltage system should be shut down and restarted. Finally, the smart documentation helps both technicians and engineers manage highly complex systems by seamlessly providing needed part information for diagnosis and repair.

The after-sales service and maintenance of vehicles will only become more critical as vehicles become increasingly electrified and autonomous. These vehicle technologies create new challenges and concerns for service technicians as they repair and maintain customers' vehicles. With advanced electrical systems engineering solutions, automotive companies can equip service technicians with the tools they need to overcome the challenges of maintaining such vehicles. This will ensure that vehicles continue to operate safely and efficiently as they move people and goods throughout the world.

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