

THE EVOLUTION OF AUTOMOTIVE DIAGNOSTICS: FROM CLASSIC MECHANICS TO ADVANCED ELECTRONICS AND THE ROLE OF CONTINUOUS TRAINING

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Abstract: This text aims to provide the reader with the historical and analytical framework that contextualizes the other contributions: the trajectory of automotive diagnostics, from the empirical procedures of classical mechanics to the latest generation of electronic systems, and the direct consequence of this path for the training of professionals in the sector. The choice of this focus is not accidental—it is the premise without which any discussion about contemporary automotive technology remains unsupported. The central thesis that runs throughout the text is that the competitiveness and operational safety of contemporary workshops depend, increasingly and inseparably, on two complementary dimensions: the incorporation of advanced diagnostic technologies and the systematic investment in the continuous training of technicians. Neither of these dimensions is sufficient in isolation. The chapter also argues that this equation has specificities in the Brazilian context that need to be understood for any professional training agenda to be effective.

Keywords: automotive diagnostics, mechanics, electronics

INTRODUCTION: THE WORKSHOP AS A TECHNOLOGICAL ORGANIZATION

The automobile is, today, one of the most complex technological systems in everyday use. A

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passenger vehicle produced from the second half of the 2010s onward may contain between 50 and 150 electronic control units (ECUs), dozens of sensors distributed across all of its functional areas, proprietary internal communication protocols, and remote software update systems (OTA — Over-the-Air). This complexity, which constitutes the most visible face of the so-called fourth industrial revolution applied to transportation, has structurally transformed the nature of the work performed in automotive repair workshops.

If, in the 1960s and 1970s, the diagnosis of a vehicle was predominantly a sensory and empirical exercise — based on listening to the engine, the feel of the parts, and the accumulated experience of the mechanic — today this same process demands the mastery of computational diagnostic systems, the interpretation of standardized fault codes, the use of electronic measurement equipment, and, increasingly, an understanding of the data flows generated by connected vehicles (Rawashdeh et al., 2023; Cumin et al., 2023).

This transition is not only technological; it is profoundly organizational and human. It requires automotive workshops to reinvent themselves as knowledge organizations — no longer centers of specialized manual labor, but environments of continuous learning, in which the technical updating of professionals is a condition of competitive survival and of responsibility toward user safety. Knowledge management, a concept developed in the management sciences to describe the processes by which organizations create, share, and apply knowledge (Abdi et al., 2018), thus becomes an inescapable strategic dimension for any workshop that aspires to provide quality services in the contemporary automotive context.

This chapter is organized into eight substantive sections, in addition to this introduction and the final considerations. Sections 2 and 3 examine the origins of automotive diagnostics and the advent of the OBD-II standard. Section 4 discusses advanced electronics, predictive maintenance, and the IoT. Section 5 addresses electric and hybrid vehicles. Section 6 deals with knowledge management. Section 7 contextualizes the Brazilian scenario. Section 8 presents pedagogical models and strategies for training the automotive technician of the 21st century.

FROM THE ORIGINS TO CLASSICAL DIAGNOSTICS: EMPIRICAL KNOWLEDGE AND SYSTEMATIZED MECHANICS

The Pre-Electronic Period: The Technician as a Diagnostic Instrument

The first decades of the automotive industry, extending approximately from the beginning of the 20th century to the mid-1970s, were characterized by an essentially empirical diagnostic logic. The vehicles of the time — equipped with internal combustion engines with relatively simple mechanical and electrical systems, carburetors, breaker-point ignition systems, and manual transmissions without electronic controls — could, to a large extent, be diagnosed and repaired based on the sensory experience accumulated by the technician.

The knowledge of the classical mechanic was, in essence, tacit — to use the conceptualization of Nonaka and Takeuchi (1995), revisited in the automotive context by Abdi et al. (2018). It was an embodied form of knowledge, transmitted through the observation and imitation of more experienced professionals, hardly verbalizable and practically untransferable by written or formal instructional means. Listening to the engine “knock” and identifying whether it was detonation or piston slack; feeling the temperature of the exhaust piping and inferring the operation of the injection system; identifying the specific smell of a short circuit or of a degrading timing belt — these were the diagnostic instruments of the technician trained in the tradition of classical mechanics.

This model, although effective within the limits of the technology of the time, presented structural fragilities that would become increasingly problematic: dependence on key professionals whose knowledge was not documented; the difficulty of diagnosing intermittent faults or faults with multiple causes; and the practical impossibility of keeping pace with technological innovation based on empirical knowledge alone.



The Systematization of Diagnostics: From Proprietary OBD to the Threshold of Standardization

From the 1980s onward, the progressive introduction of electronic control systems — especially the electronic fuel injection system and the first engine control modules (ECUs) — brought with it the first embedded self-diagnostic features. These primitive on-board diagnostics (OBD) systems were proprietary to each automaker, non-standardized, and accessible only through equipment and software specific to each manufacturer, which imposed significant access barriers on independent workshops.

The period between the mid-1980s and 1996 may be called the “proprietary OBD era”: each automaker developed its own fault codes, its own connectors, and its own communication protocols, creating a fragmented environment that favored authorized networks and penalized the independent repairer. Attempts at partial standardization — such as the SAE J1978 standard of 1994, which established minimum requirements for diagnostic scanners — indicated that the industry recognized the problem, but the market awaited a more comprehensive regulatory solution.

That solution came by force of government regulation. In the United States, following the enactment of the Clean Air Act Amendments of 1990, the Environmental Protection Agency (EPA) began to require that all vehicles produced for the American market be equipped with on-board diagnostic systems capable of detecting faults that could compromise pollutant emissions. This regulatory imperative was the seed of the OBD-II standard, which would come into force in 1996 — the most significant technological milestone in the history of automotive diagnostics in the 20th century (Cumin et al., 2023).



THE OBD-II STANDARD: UNIVERSALIZATION AND DEMOCRATIZATION OF DIAGNOSTICS

Fundamentals and Architecture of the OBD-II System

The OBD-II standard (On-Board Diagnostics, Second Generation) established, for the first time in the history of the automotive industry, a universal diagnostic protocol, applicable to all vehicles sold in the United States from 1996 onward — a requirement that progressively spread to other global markets over the following decades, including Brazil, where the system became mandatory for light vehicles from 2007, by force of CONAMA Resolution No. 403/2008 and the PROCONVE regulations. Its architecture is based on three central elements: the DLC (Data Link Connector), positioned in a standardized location on the vehicle’s dashboard; the DTCs (Diagnostic Trouble Codes), which identify anomalies in the monitored systems; and the PID parameters (Parameter IDs), which allow the real-time reading of operational variables of the vehicle, such as engine temperature, accelerator position, intake manifold pressure, and engine speed (Cumin et al., 2023).

The universalization of the connector and of the basic communication protocols — CAN, ISO 9141-2, SAE J1850, and KWP2000 — was what truly democratized automotive diagnostics. For the first time, an independent workshop, without ties to any specific automaker, could connect a multi-brand scanner to a vehicle from any manufacturer and access basic diagnostic data. This leap transformed the competitive structure of the automotive repair sector, reducing dependence on the so-called “authorized workshops” and broadening access to qualified technical diagnostics.

The OBD-II system revolutionized the automotive industry by enabling the real-time monitoring of key vehicle parameters, such as engine load, speed, accelerator position, and diagnostic trouble codes, providing a standardized interface that transcends the barriers between manufacturers (Rawashdeh et al., 2023, p. 458, our translation).



Limits and Complementarities of OBD-II Diagnostics

Despite its transformative impact, OBD-II presents structural limitations that became more evident as vehicles incorporated electronic systems of increasing complexity. The standard primarily covers systems related to emissions — engine, automatic transmission, exhaust system, and catalytic converter — leaving outside its mandatory scope a series of critical systems, such as ABS (Anti-lock Braking System), airbags, electronic suspension, electromagnetic brakes, electric power steering, and the increasingly complex advanced driver assistance systems (ADAS). To access these systems, automakers develop proprietary protocols — the so-called OEM (Original Equipment Manufacturer) protocols — which recreate, at a more sophisticated level, the fragmentation that OBD-II had partially overcome (Cumin et al., 2023; Rawashdeh et al., 2023).

This dynamic has direct implications for the business model of independent workshops and for the training of their technicians. Specialization by brand or by family of systems increasingly becomes a strategy of competitive differentiation — and a quality requirement that cannot be met without continuous investment in training and in updating diagnostic tooling. Access to proprietary diagnostic systems has become, over the last two decades, one of the main factors of competitive inequality between authorized networks and independent workshops.

THE ERA OF ADVANCED ELECTRONICS: EMBEDDED SYSTEMS, IOT, AND PREDICTIVE DIAGNOSTICS

The Multiplication of Electronic Systems and the New Diagnostic Complexity

The first decade of the 21st century marked the beginning of a new phase in automotive electronics, characterized by the proliferation of specialized ECUs, the development of high-speed internal communication networks (especially the CAN — Controller Area Network — bus), and the growing integration of vehicle systems into shared computational architectures. A mid-segment



vehicle produced in 2024 may contain more than 100 ECUs communicating simultaneously over internal networks. Systems such as dual-clutch transmissions, electronically controlled adaptive suspension, regenerative braking in hybrids, and driver assistance systems (ADAS) depend on the coordinated interaction of multiple electronic units whose faults rarely manifest in isolation.

This level of integration imposes a new diagnostic challenge: identifying the root cause of a fault when the symptoms manifest in one system, but the origin lies in another, interconnected through the internal communication network. The professional who works only with DTC reading — without mastery of the communication flows between ECUs and without tools capable of monitoring these flows in real time — will face increasing difficulties in performing accurate diagnoses in this scenario. Mahale et al. (2025) document that the integration of artificial intelligence into the diagnostic process, especially for the interpretation of multiple simultaneous signals from distinct ECUs, represents one of the most promising advances of advanced electronic diagnostics.

Predictive Maintenance, IoT, and Connected Vehicles

The most disruptive advance of the last decade in the field of automotive diagnostics is the transition from reactive diagnostics — performed after the manifestation of a fault — to predictive diagnostics, which anticipates the fault before it compromises the functioning or safety of the vehicle. This transition is made possible by the convergence of three technologies: high-precision embedded sensors, the connectivity of vehicles to the internet (automotive IoT), and machine learning algorithms capable of identifying degradation patterns in the data generated by the sensors.

Cumin et al. (2023), in a study presented at the International Conference on Organization and Technology of Maintenance, demonstrated that OBD-II systems, when integrated with cloud connectivity platforms, offer diagnostic capabilities significantly superior to those of static reading equipment, allowing the continuous monitoring of vehicle status and the generation of predictive alerts before the fault code is formally activated. The authors emphasize that this capability is especially



relevant for commercial fleets, where the unplanned unavailability of vehicles represents a significant operational cost.

At the data level, connected vehicles generate significant volumes of operational information with each use cycle — data on engine behavior, brake system wear, the driving profile, and, in electrified vehicles, the state of the batteries. The analysis of these data by machine learning algorithms — applied to the set of variables recorded by OBD-II and by proprietary sensors — opens diagnostic perspectives that transcend the capabilities of conventional equipment. Rawashdeh et al. (2023) found that intelligent OBD-II-based diagnostic systems are capable of detecting operational anomalies before the generation of formal DTCs, significantly broadening the window of preventive intervention.

Mahale et al. (2025), in a study published by the Asian Institute of Research, proposed a conceptual framework integrating Augmented Reality (AR), Artificial Intelligence (AI), and IoT for OBD-II-based vehicle diagnostics, demonstrating that overlaying diagnostic data directly onto the vehicle's parts — through AR glasses — reduces diagnostic errors and decreases vehicle downtime. This type of technology points to a near future in which the automotive technician will operate in an augmented information environment, with instantaneous access to diagnostic data and technical procedures integrated into their field of vision.

ELECTRIC AND HYBRID VEHICLES: NEW DIAGNOSTIC PARADIGMS AND NEW RISKS

The Electrification of the Fleet and its Impacts on Maintenance

The growing electrification of the global automobile fleet probably represents the greatest disruption in the history of automotive diagnostics and maintenance since the introduction of OBD-II. Battery electric vehicles (BEVs) and plug-in hybrids (PHEVs) introduce high-voltage systems — typically between 200 and 800 Volts, depending on the architecture — that require safety protocols radically different from those applicable to conventional 12-Volt vehicles. The improper handling of



high-voltage systems represents a real risk of fatal electrocution for technicians who are not properly trained.

Beyond the electrical risk, BEVs introduce new systems that have no functional equivalent in internal combustion vehicles: the battery management system (BMS), which continuously monitors temperature, state of charge (SoC), state of health (SoH), and cell balancing; the battery thermal management system; the traction inverters; the electric motors; and the on-board chargers. Each of these systems has its own diagnostic logic, with specific parameters and fault codes that do not fit the generic standards of classical OBD-II.

Alkhamaiesh and Cavanaugh (2023), in a study published in the journal *Modern Economy*, analyzed the process of preparing qualified automotive technicians for the transition to electric vehicles in the United States and concluded that the skills gap in the sector is critical and structural. The authors identify that technologies such as the digital twin and virtual reality (VR) can be used to create immersive and realistic training environments for electric vehicle technicians, allowing the simulation of failure scenarios and maintenance procedures without exposure to the real risk of the high-voltage environment.

The Challenge of the Skills Gap

The Institute of the Motor Industry (IMI), in the United Kingdom, estimated in 2022 that an additional 90,000 qualified technicians would be needed to handle the volume of services generated by the electric vehicle fleet projected for British roads by 2030. The pace of training these professionals, experts warn, falls short of what is necessary to meet the demand (IMI, 2022). This warning is consistent with the findings of Battisti et al. (2025), who developed a competency framework for BEV maintenance technicians, composed of four central categories — Professional Knowledge, Professional Skills, Professional Attitude, and Personal Qualities — subdivided into 24 subcategories and 106 specific indicators, derived from a Delphi study with 15 industry experts.

Battisti et al. (2025) conclude that the competency framework for BEV technicians goes substantially beyond technical mastery of electronic systems: it encompasses competencies in high-voltage electrical safety, diagnosis of battery management systems, interpretation of telemetry data and — equally relevant — attitudes of continuous learning and adaptability in the face of a rapidly evolving technology. The attitudinal dimension, the authors emphasize, is frequently underestimated in traditional technical training curricula, but it is decisive for professional sustainability in a sector of such accelerated technological change.

KNOWLEDGE MANAGEMENT AND CONTINUOUS TRAINING: THE COMPETITIVE DIFFERENTIAL

Knowledge as a Strategic Asset of the Workshop

The theory of knowledge management, whose foundations were systematized by Nonaka and Takeuchi (1995) in the SECI model (Socialization-Externalization-Combination-Internalization), offers a powerful analytical framework for understanding the dynamics of organizational learning in automotive workshops. In summary, the SECI model describes how tacit knowledge — that which the most experienced technicians carry with them and which manifests in their diagnostic capacity — can be systematically converted into explicit, documented, shared knowledge incorporated into the routines of the organization.

Abdi et al. (2018), in a study published in the *Journal of Business Economics and Management*, empirically investigated the effect of knowledge management, organizational culture, and organizational learning on the innovation capacity of companies in the automotive sector, demonstrating that the systematic management of knowledge has a positive and statistically significant impact on innovation and on sustainable competitive advantage. Although the study was conducted with large automakers and suppliers, its findings are transferable to the context of independent workshops, provided that the specificities of scale are considered: the difference between a workshop that grows and one that



stagnates frequently lies in the capacity of the former to convert the knowledge of its technicians into documented, replicable, and transmissible processes.

Knowledge management in an automotive workshop manifests in concrete practices, among which the following stand out: the documentation and archiving of diagnostic histories by vehicle and by model; the creation of internal technical libraries with solutions for recurrent faults; periodic case-sharing meetings among the team; participation in technical communities for knowledge exchange; and — crucially — the establishment of formalized training routines that ensure that external knowledge is regularly incorporated into the collective repertoire of the team.

The Virtuous Cycle of Continuous Training

The acceleration of the technological innovation cycle in modern vehicles — with software updates that occur in real time via OTA, new driver assistance systems launched with each new generation of models, and the growing penetration of electrified vehicles — makes continuous training no longer a differential, but a basic requirement of professional competence. Technicians trained five years ago in conventional technical courses already find, in the most recent vehicles, systems for which their initial training did not prepare them.

Firmansyah et al. (2022), in a study on organizational learning and leadership in professional education contexts published in the journal *Frontiers in Psychology*, demonstrated that the collective capacity of an organization to acquire, process, and apply new knowledge is strongly mediated by transformational leadership and by formalized knowledge management practices. This relationship, although identified in the context of professional technical education, is directly applicable to the environment of automotive workshops: organizations whose managers value, encourage, and enable continuous technical updating build, over time, sustainable competitive advantages that are difficult to replicate by competitors who treat training as an avoidable cost.

In the international market, structured continuing-education programs — such as the



Worldpac Training Institute, which offers hundreds of courses annually in various technical and managerial modalities — exemplify the professionalization of continuing education in the sector (Worldpac Training Institute, 2026). The senior training director of Worldpac identified in 2026 three dominant trends in the demand for training: training in high-voltage vehicles; the growing mastery of electronics as a fundamental diagnostic skill; and the development of business management competencies for workshop owners.

THE BRAZILIAN SCENARIO: ELECTRIFICATION, TRAINING, AND CHALLENGES OF THE REPAIR SECTOR

The Expansion of the Electrified Fleet in Brazil and its Implications for Workshops

In the first half of the 2020s, Brazil is experiencing an unprecedented acceleration in the electrification of its vehicle fleet. According to the Brazilian Electric Vehicle Association (ABVE), the national market recorded 177,358 registrations of light electrified vehicles in 2024, a mark that was already surpassed in November 2025, with 190,007 units registered over the first eleven months of the year — consolidating 2025 as the most significant year of electromobility in the country. The total fleet of electric and hybrid vehicles in circulation in Brazil reached approximately 590,000 units at the end of 2025, representing about 9.4% of the Brazilian automotive market (ABVE, 2025).

Long-term projections indicate that this trajectory will intensify. The Energy Research Company (EPE, 2023), in a technical note on the energy demand of light vehicles for the period 2024–2033, projects that electrified vehicles could represent up to 23% of the annual licensing of light vehicles in Brazil by 2035, equivalent to 784,000 units per year. More accelerated scenarios, contemplated by ANFAVEA and BCG, project a share of 35% to 42% of electrified vehicles in the total fleet by 2040.

This dizzying growth imposes on the Brazilian automotive repair network an urgent and concrete challenge: the more than 121,000 mechanical workshops in operation in the country —



which generate more than 760,000 direct and indirect jobs and move around R\$ 128 billion annually in maintenance services, according to data from Sindirepa-SP — will need, within a relatively short time horizon, to be prepared to receive, diagnose, and repair vehicles whose technical systems are fundamentally distinct from those for which the majority of their professionals were trained (Sindirepa-SP, n.d.; SEBRAE, 2020).

The National Technical Training Ecosystem: Advances and Gaps

The main technical training institution for the automotive sector in Brazil is SENAI (National Industrial Apprenticeship Service), which offers, in its units distributed throughout the national territory, technical automotive maintenance courses lasting 18 to 24 months, covering mechanical, electrical, and electronic systems and, increasingly, electrified vehicle technologies. In response to the emerging demand for qualification in electromobility, SENAI began, from 2024, to structure specific offerings for electric vehicles: SENAI of Rio Grande do Norte, for example, launched in 2024 the courses “Principles of the Electric Vehicle,” “Safe Work on High-Voltage Electric Vehicles,” and “Electric Vehicle Converter and Maintainer,” with course loads of 20 to 160 hours (SENAI-RN, 2024).

In 2026, SENAI Paraná took a structural step by launching, during the Autopar Fair, the Workshop of the Future (Oficina do Futuro) program — developed in partnership with Sindirepa-PR and Sebrae/PR — a structured consulting initiative aimed at preparing micro and small workshops for the new reality of electromobility. The program, with a total duration of 38 hours across in-person and remote activities, covers a diagnosis of the electrical infrastructure, operational assessment, compliance with safety standards, process organization, and technical training of the teams, with a 50% subsidy of the investment by Sebrae/PR (SENAI Paraná, 2026). The initiative is significant precisely because it recognizes that the most critical barrier for the majority of independent workshops is not a lack of willingness to update, but the lack of structure and support to do so.

In the field of professional certification, Brazil has the IQA (Automotive Quality Institute)



— a non-profit certification body created by Anfavea, Sindipeças, Sindirepa, and other entities — which develops competency-based certification tests for automotive professionals. However, unlike the North American ASE system or the British IMI TechSafe, the IQA still operates at a limited scale and recognition, without constituting a credential widely required by the market. The absence of a robust and widely recognized national professional certification system is one of the most critical gaps in the Brazilian automotive technical training ecosystem (Portal da Reparação, n.d.).

The Particular Challenges of Micro and Small Workshops

The structure of the Brazilian automotive repair sector is dominated by micro and small enterprises. In São Paulo, the largest market in the country, there are more than 28,000 vehicle repair establishments in this category, according to Sindirepa-SP. These companies face challenges that structurally differentiate them from authorized networks: limited financial resources for investment in next-generation diagnostic equipment; difficulty in accessing and paying for continuing-education programs; high turnover of qualified technicians, who migrate to dealerships with higher pay; and, especially, the prohibitive cost of diagnostic equipment for high-voltage vehicles, which requires significant investments in PPE, battery system analyzers, and proprietary adapters.

Programs such as the Legal Workshop Project (Projeto Oficina Legal), developed by Sebrae/PE in partnership with Sindirepa-PE since 2022, demonstrate that structured interventions for training in management and quality — including the 5S methodology — can produce significant results even in micro and small workshops: in 2024, 63 establishments were certified at the end of the program, with documented positive results in productivity and internal organization (SEBRAE Agência de Notícias, 2024). This experience shows that the path to the modernization of Brazilian independent workshops necessarily passes through subsidized programs, partially funded by the public authorities or by sector entities, that reduce the financial barriers to access to training and to diagnostic technologies.

The specificity of the Brazilian context also imposes a consideration that frequently escapes

analyses based exclusively on international experiences: the coexistence, in the circulating fleet, of technologies from multiple generations. A typical Brazilian automotive workshop serves, on the same day, carbureted vehicles from the 1980s, models with OBD-II from the 2000s, automobiles with ADAS systems from the 2010s and, increasingly, hybrids and electrics. This simultaneous technological plurality requires of the technical teams a capacity to move between different diagnostic paradigms — from classical sensory inspection to the latest-generation scanner — that has no equivalent in most international contexts where fleet renewal is more accelerated.

MODELS AND TRAINING STRATEGIES FOR THE 21ST-CENTURY AUTOMOTIVE TECHNICIAN

Contemporary Pedagogical Approaches

The pedagogy of automotive technical training is undergoing a process of accelerated renewal, driven by the same technological forces that are transforming vehicles. Traditional approaches — based on theoretical lectures followed by laboratory practices with didactic vehicles — are proving increasingly insufficient to prepare technicians capable of operating competently on high-voltage electrified vehicles, whose fault conditions cannot be easily reproduced in conventional pedagogical environments without risk of accidents.

Maksum et al. (2024), in a study published in the *International Journal of Education in Mathematics, Science and Technology*, proposed the TEFA-PBL (Teaching Factory with Problem-Based Learning) model, which integrates the principles of the teaching factory — where students carry out real productive activities in an educational environment — with the problem-based learning methodology. The results of the study demonstrated that this model produces significant improvements in the problem-solving and technical communication competencies of automotive students, skills that are especially relevant in the diagnosis of complex electronic systems.

Virtual reality (VR) and augmented reality (AR) emerge as high-potential pedagogical



technologies for training in high-voltage systems. As documented by Alkhamaiesh and Cavanaugh (2023), immersive VR-based training environments allow trainee technicians to practice maintenance procedures on electric vehicles under zero-risk conditions, with immediate feedback on procedural errors that, in a real context, could result in serious accidents. The scalability of this approach represents a significant logistical and economic advantage for training institutions with limited resources, as is the case of many Brazilian technical schools and federal institutes.

Professional Certification as a Mechanism of Quality and Trust

In the international context, professional certification systems such as ASE (Automotive Service Excellence) in the United States and IMI TechSafe in the United Kingdom offer the market a mechanism for signaling verified and up-to-date technical competence. These systems require professionals to periodically renew their certifications, ensuring that the accreditation reflects the current state of the technician's knowledge, and not just their initial training. The robustness of these systems lies in their independence from specific automakers and in their broad coverage of competencies — characteristics that the future Brazilian national certification system will likewise need to incorporate.

The construction of a robust and widely recognized national automotive diagnostics certification system — with specific tracks for OBD-II, advanced electronics, ADAS systems, and electrified vehicles — will require coordination among the IQA, SENAI, Sindirepa, Anfavea, and the Ministry of Education. This is a medium-term agenda whose urgency grows in proportion to the pace of electrification of the Brazilian fleet.

The Safety Dimension as a Pedagogical Imperative

Any training program for technicians who work with electrified vehicles must incorporate,

as a non-negotiable element, training in high-voltage electrical safety. The risk of electrocution in systems that operate between 200 and 800 Volts is real and potentially fatal if the system deactivation procedures are not rigorously followed. The correct use of specific Personal Protective Equipment (PPE) — dielectric gloves of the appropriate class, insulating footwear, and safety glasses —, the application of the lockout/tagout procedure on high-voltage systems, and knowledge of the emergency protocols in the event of an accident are fundamental competencies that precede any diagnostic skill on electric vehicles.

Battisti et al. (2025) emphasize that the safety dimension is transversal to all four categories of the competency framework they developed, which shows that safety should not be treated as an isolated module, but as a guiding principle that permeates all professional practices of the electric vehicle technician. In the Brazilian context, the “Safe Work on High-Voltage Electric Vehicles” program, offered by SENAI-RN (2024) as one of the first courses specific to electromobility in the country, represents a structural step in this direction — and a model to be replicated by other units of the “S System” throughout the national territory.

FINAL CONSIDERATIONS

The journey traced throughout this chapter — from the empirical origins of classical automotive diagnostics to predictive systems based on artificial intelligence and IoT, passing through the OBD-II standard, the revolution of electrified vehicles, and the specificity of the Brazilian context — clearly demonstrates that the history of automotive diagnostics is inseparable from the history of professional learning and adaptation. Each technological advance in vehicles created, simultaneously, new diagnostic possibilities and new competence requirements for the technicians responsible for operating them.

Four central conclusions emerge from the analysis developed in this chapter. The first is that contemporary automotive diagnostics is irreducibly systemic: it is not possible to competently

diagnose modern vehicles without mastery of the communication flows between integrated electronic systems. The second is that the electrification of the fleet represents a paradigm shift that imposes the urgent revision of technical training curricula and the creation of certification systems that ensure that only properly qualified professionals intervene in high-voltage systems.

The third conclusion is that Brazil is experiencing a moment of inflection: the acceleration of electrified vehicle sales — with more than 190,000 units registered in just the first eleven months of 2025 (ABVE, 2025) — is approaching the point at which the gap in professionals qualified to service them will go from latent to acute. Programs such as the Workshop of the Future (SENAI Paraná, 2026) and the pioneering courses of SENAI-RN (2024) are initiatives that urgently need to gain scale and national reach.

The fourth conclusion, and perhaps the most strategic for workshop managers, is that investment in continuous training is the most profitable of the investments a workshop can make. A workshop whose technicians are capable of accurately diagnosing advanced electronic systems, hybrid and electric vehicles, and ADAS systems legitimately charges for a service of greater added value, drastically reduces rework, earns the lasting trust of its customers, and positions itself in a competitively superior way in a market that will inevitably make these services the norm.

Among the gaps that this chapter could not cover — and that constitute a relevant research agenda — the following stand out: empirical studies on the financial impact of diagnostic modernization in Brazilian micro and small workshops; comparative analyses of SENAI's electromobility training programs in different states; and investigations into the behavioral and cultural mediators of the adoption of new diagnostic technologies by technicians trained in the tradition of classical mechanics.

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