EVIDENCE-CLASSIFIED DIAGNOSIS OF INTERCONNECTED IGNITION-COIL, CONNECTOR, AND CONTROL-UNIT DRIVER FAULTS

Joyfull Sidney Payumi [1*] Nodi Poluan Sompie [2] Franklin Bawano [3]
[1,2,3] Politeknik Negeri Manado, Indonesia.
*Corresponding Author: Joyfull Sidney Payumi.

ABSTRACT
Coil-on-plug (COP) ignition faults can involve the coil, connector, harness, and electronic control unit (ECU), yet a single workshop case cannot establish the initiating component or transient chronology. This evidence-classified diagnostic case examined one Daihatsu Xenia 1.0 Non-VVT-i with an EJ-DE three-cylinder gasoline engine presenting vibration, misfire, reported loss of power, and reported increased fuel consumption. The available field record documented visual inspection, multimeter observations of supply and ignition trigger/feedback (IGT/IGF) lines, coil substitution, guarded substitution with a known-good ECU, on-board diagnostics II (OBD-II) scanning, internal ECU and connector inspection, corrective repair, and preliminary workshop verification. The multimeter did not detect comparable IGT/IGF indications on cylinders 2 and 3; replacing the suspected coils did not resolve the symptoms; and the donor ECU displayed diagnostic trouble codes (DTCs) P0300, P0352, P0353, and P0171. Degraded female connector contacts and visible damage along the original ECU ignition-driver path were subsequently observed. Repair of the documented defects was followed by restored continuity and stable operation during an unspecified workshop observation period. The evidence supports system-level diagnosis of an interconnected coil-connector-ECU fault, but not a proven cascade from coil switching to ECU damage. The principal contribution is a transparent reporting framework that separates direct observation, diagnostically supported interpretation, and unmeasured mechanism. The case also provides a safety-conscious diagnostic sequence for workshop and proposed vocational-learning use.

Keywords: Automotive diagnostics, coil-on-plug ignition, diagnostic evidence classification, electronic control unit driver, failure analysis.

INTRODUCTION

Modern vehicle powertrains depend on electronic control units (ECUs) to coordinate fuel injection, ignition timing, feedback monitoring, and fail-safe functions. In a coil-on-plug (COP) system, each ignition coil repeatedly stores and releases magnetic energy under ECU command. A defect in the coil, igniter, connector, power supply, ground path, or wiring harness can affect both combustion quality and the electronic driver that controls the circuit. Because these faults may present as intermittent misfire, reduced power, unstable idling, or excessive fuel consumption, diagnosis must distinguish an initiating defect, concurrent faults, and secondary damage.

Automotive electrical systems are exposed to conducted disturbances produced by load switching and supply interruption. ISO 7637-2 and SAE J1113/11 specify controlled methods for evaluating transient phenomena and immunity in vehicle electrical systems (International Organization for Standardization [ISO], 2011; SAE International, 2023). Ignition-system models further demonstrate that coil inductance, coupling, circuit resistance, spark-gap conditions, and switching parameters influence transient voltage, current, and delivered spark energy (Stevenson et al., 2007; Yu et al., 2016). These principles make an ignition-coil circuit a technically plausible source of electrical stress; however, direct waveform and current measurements are required before a transient magnitude, propagation path, or component-stress sequence can be claimed for this case.

Connector condition is equally important. Experimental and field-based studies show that fretting, insufficient contact force, and imperfect crimp interfaces can produce intermittent or elevated contact resistance (Liu & Heaton, 2002; Swingler, 2000). High-resistance automotive connections may also develop measurable temperature rise under load (Modi & Galgoci, 2020). The broader electrical-contact literature demonstrates that vibration and thermal cycling can promote fretting, oxide accumulation, and unstable resistance (Antler, 1981, 1985; Swingler, 2009), while surface morphology and interacting degradation mechanisms influence connector durability (Liskiewicz et al., 2020; Song et al., 2025). These findings justify inspecting connector contacts and crimp joints when a circuit fault persists after component substitution, but they do not establish that every degraded connector was caused by the same initiating event.

Published work on ignition-system modeling, standardized diagnostic trouble codes, failure modes and effects analysis (FMEA), fault-tree analysis, and machine diagnostics provides established ways to characterize component behavior, standardize fault information, and structure competing explanations (International Electrotechnical Commission [IEC], 2018; ISO, 2025; SAE International, 2025; Stevenson et al., 2007; Vesely et al., 1981; Yu et al., 2016). However, these approaches are rarely combined in workshop case reports that explicitly grade each statement by evidentiary strength. The novelty of this manuscript is therefore not a newly proven electrical failure mechanism. It is an evidence-classified reporting and diagnostic sequence that links direct observations, a supported system-level interpretation, unresolved alternatives, and the response to corrective work within one complex workshop case.

Automotive education studies have used electronic-control-unit trainers, monitoring systems, electronic-fuel-injection scanners, and teacher training to strengthen practical understanding of electronically controlled engines (Adnyana & Suyanto, 2013; Echsony & Nurfaizin, 2018; Ridhuan et al., 2023; Sukma & Wailanduw, 2020). More broadly, research on troubleshooting and diagnostic competence indicates that authentic problem solving, scaffolding, and coached practice are central to professional diagnostic learning (Chernikova et al., 2020; Johnson et al., 1993; Jonassen, 2000; Lajoie & Lesgold, 1992), while problem-based learning can help learners integrate conceptual and procedural knowledge (Hmelo-Silver, 2004). A recent engineering-education review likewise identifies troubleshooting as underrepresented despite its importance for industry readiness (Fatokun & Gumbo, 2024). The present manuscript does not evaluate a teaching intervention or student-learning outcome. Its education-facing contribution is limited to proposing an authentic case resource for circuit tracing, diagnostic-trouble-code interpretation, measurement-limit recognition, safe substitution planning, evidence classification, and explicit documentation of uncertainty.

The research gap lies in the limited transparent documentation of diagnostic episodes in which ignition-coil circuit abnormalities, connector degradation, and ECU ignition-driver damage coexist, while the initiating event remains uncertain. This study therefore aimed to (1) reconstruct the available diagnostic sequence for one Daihatsu Xenia 1.0 Non-VVT-i case; (2) separate observed coil, signal, connector, ECU, and DTC findings from interpretations; (3) test whether convergent evidence supports an interconnected system-level fault; and (4) formulate a cautious troubleshooting sequence with explicit safety and reporting boundaries. The scholarly contribution is an operational evidence-classification framework for case reporting, not universal experimental proof of a new cascade mechanism.

Transferability is analytical rather than statistical. The transferable elements are the system-level reasoning sequence, explicit classification of evidentiary strength, configuration-specific DTC recording, and control of causal claims. Vehicle-specific elements include igniter integration, ECU protection strategy, connector geometry, IGT/IGF architecture, immobilizer requirements, scan-tool behavior, and manufacturer DTC logic. The workflow should therefore be adapted rather than copied directly across vehicle makes and generations.

Figure 1 operationalizes three evidence levels. “Directly observed” requires a recorded visual, instrument, scanner, substitution, or repair-response observation. “Diagnostically supported” requires convergence of at least two independent observations without a better-supported competing explanation. “Hypothesized” is reserved for mechanisms or chronology requiring uncollected waveform, resistance, thermal, temporal, or component-level evidence.

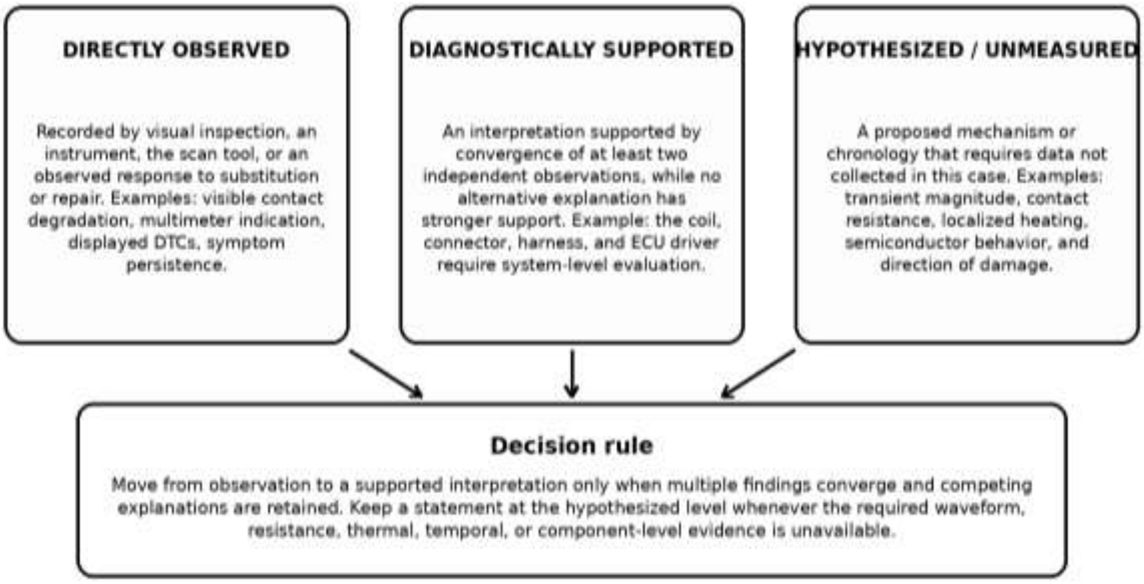

Figure 1. Operational evidence categories and decision rules used in the diagnostic case.

METHOD

Study design and scope

This study used a single-vehicle diagnostic case-study and failure-analysis design at MotoXpress Otomoto Autocare Workshop in Wanea, Manado. The case involved a Daihatsu Xenia 1.0 Non-VVT-i with an EJ-DE engine. For reporting purposes, the case is treated as purposive because no consecutive sampling frame, eligibility log, or case-series denominator was available. It was reconstructed from an existing field record that documented one sequential diagnosis-and-repair episode. The fault was not deliberately induced, no control vehicle was used, and no randomized or repeated experiment was conducted. Consequently, the study evaluates internal diagnostic coherence and does not claim controlled causal identification.

Case definition and baseline documentation

The investigation began with a review of ignition-system operation, ECU control, electromagnetic disturbance, connector reliability, diagnostic standards, and relevant failure-analysis approaches. The available field record identified the vehicle model and engine configuration but did not preserve the model year, odometer reading, complete service history, prior ECU or ignition repairs, or environmental-exposure history. No unsupported values were reconstructed. These omissions restrict assessment of age-related degradation, moisture exposure, prior connector work, and earlier electrical intervention as alternative causes.

The field record described engine vibration, repeated misfire, reported reduced power, and reported increased fuel consumption. The last two symptoms were not quantified by dynamometer, fuel-flow, emissions, or standardized road testing. Initial inspection covered the ignition coils, visible wiring condition, connector contacts, available power and ground references, and the ECU-related ignition circuit. This stage generated candidate explanations before any component substitution.

Case identification focused on five pre-specified evidence domains: (1) visible coil and connector condition; (2) available supply, IGT, IGF, and ground-reference indications; (3) persistence or resolution of symptoms after coil substitution; (4) configuration-specific DTC behavior during donor-ECU substitution; and (5) visible findings along the original ECU ignition-driver path and the subsequent repair response.

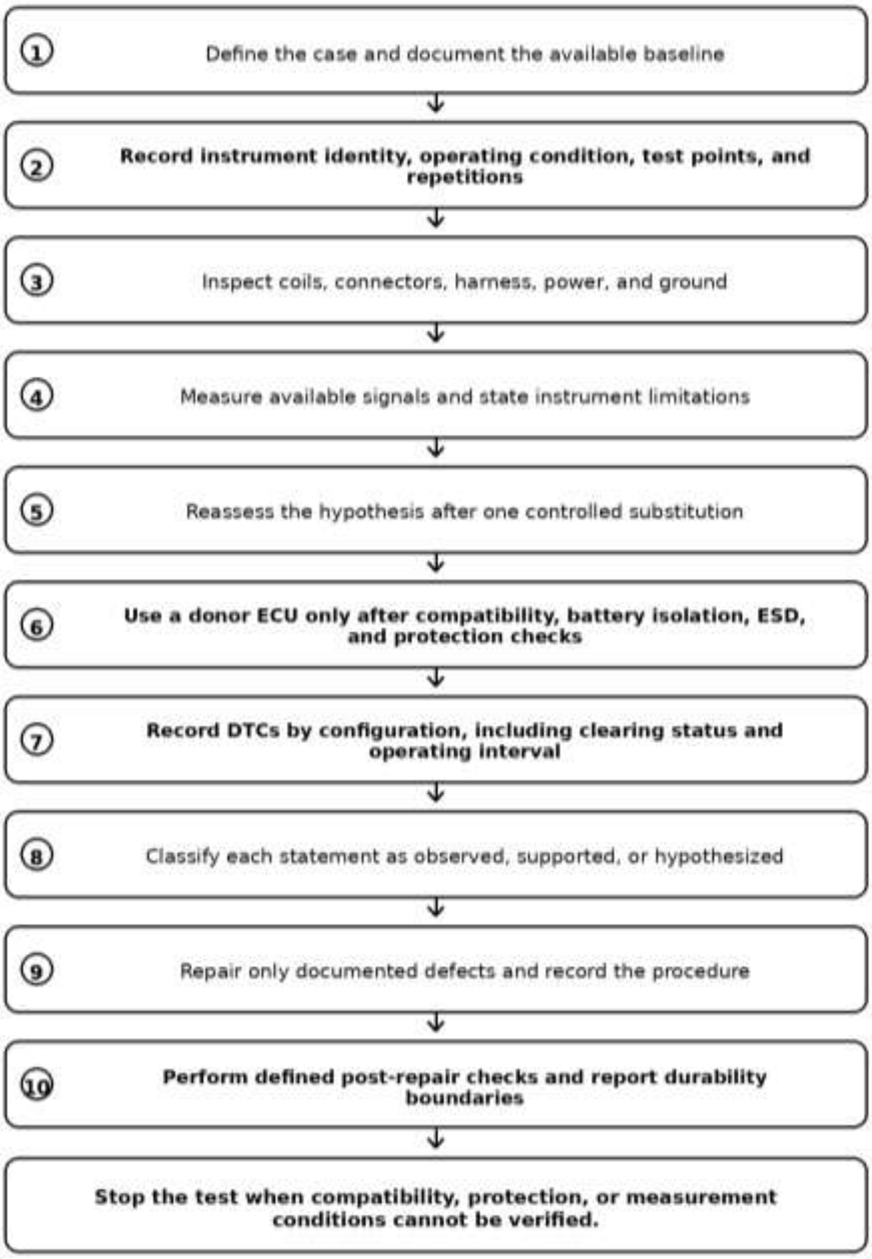

Figure 2. Revised diagnostic workflow with measurement, substitution-safety, evidence-recording, and verification checkpoints.

Diagnostic resources and measurement constraints

The diagnostic resources listed in the original field record were a digital multimeter, an ignition-coil tester, an OBD-II V1.5 scan tool, general workshop tools, replacement ignition coils, a known-good ECU, supporting circuit materials, and the Daihatsu Xenia 1.0 Non-VVT-i service book. The record stated that instruments were checked before use, but it did not retain the manufacturer, model, input impedance, accuracy class, range, sampling behavior, calibration date, uncertainty, probe configuration, exact test points, engine operating state, connector loading condition, measurement duration, number of repeated readings, or acceptance thresholds. No oscilloscope, current probe, thermal camera, micro-ohmmeter, or semiconductor curve tracer was used. The reported multimeter values must therefore be interpreted only as historical voltage indications, not as characterized IGT/IGF waveforms.

Diagnostic procedure

The available sequence proceeded from non-invasive inspection to substitution and internal inspection. First, coils, connectors, visible wiring, power, and ground were examined. Second, available supply, IGT, IGF, and ground-reference indications were observed with the multimeter. Third, suspected coils were replaced and symptoms reassessed. Fourth, because the original ECU did not provide readable DTC information, a known-good ECU was installed and the circuit was scanned. The record did not preserve donor-ECU part-number compatibility, immobilizer or initialization requirements, code-clearing status, battery-isolation procedure, electrostatic-discharge (ESD) controls, current-limiting protection, run time, start cycles, or post-test donor monitoring. The substitution is therefore reported as a historical diagnostic action rather than a fully reproducible safety protocol. In any replication, the test should stop when compatibility or protective conditions cannot be verified. Fifth, the original ECU and female contacts were inspected, documented defects were corrected, and preliminary workshop function was reassessed.

Evidence classification and analysis

The analysis used chronological diagnostic triangulation and the criteria shown in Figure 1. Evidence was classified as directly observed when it was recorded through inspection, an available instrument, the scan tool, substitution response, or repair response. A diagnostically supported interpretation required convergence of at least two independent observations and retention of unresolved alternatives. A statement remained hypothesized when it depended on unmeasured waveform, resistance, contact-force, temperature, semiconductor, or temporal evidence. Conflicting observations were not forced into the preferred sequence; instead, they reduced the certainty of the interpretation and triggered reassessment of alternative causes.

No inferential statistical analysis was appropriate because the study involved one diagnostic episode. The evidentiary criterion was internal consistency across physical inspection, voltage indications, controlled substitutions, configuration-specific DTC output, internal ECU inspection, connector inspection, corrective work, and post-repair function. Table 5 serves as a configuration-by-configuration claim-evidence matrix by linking each observation to its interpretation and reporting boundary.

Safety, authorization, and reporting boundaries

The work did not involve a human-participant intervention or collection of personal data. Nevertheless, it involved a privately owned vehicle, workshop records, invasive ECU inspection, and donor-controller substitution. The available record did not document owner authorization, battery-isolation steps, ESD controls, or donor-ECU protective checks. Because publication permission for vehicle and workshop photographs was not documented, all non-essential photographs and reproduced service-book wiring diagrams have been removed from this revised manuscript. Any future replication should obtain written owner/workshop authorization, anonymize identifying information, document electrical isolation and ESD controls, and use a compatibility-and-protection checklist before substitution testing.

RESULTS AND DISCUSSION

Baseline case and physical inspection

The investigated vehicle was reported to exhibit engine vibration, repeated misfire, reduced power, and increased fuel consumption. Reduced power and fuel use were not quantitatively measured. The model year, odometer reading, complete service history, environmental exposure, and prior electrical repairs were unavailable. Table 1 therefore distinguishes documented vehicle/service-book specifications from observations made during the diagnostic episode.

Table 1. Documented vehicle and service-book specifications

Make/model	**Daihatsu Xenia 1.0 Non-VVT-i**
Engine code	EJ-DE
Control system	Electronic control unit (ECU)
Displacement	989 cc
Configuration	Inline three-cylinder, DOHC
Maximum power	57 PS at 5,200 rpm
Maximum torque	89 N·m at 3,600 rpm
Transmission	Five-speed manual
Ignition-system type	Independent coil-on-plug (COP)
Number of ignition coils	Three; one coil per cylinder
Ignition-coil part number	Denso 90048-52126 / Daihatsu 19070-BZ010
Reported coil output	15,000-25,000 V (service-book value)
Spark-plug gap	0.8-1.0 mm
Firing order	1-3-2

Initial physical inspection identified different conditions across the three coil assemblies. Cylinder 1 showed no visible damage; cylinder 2 showed light corrosion at the socket-pin area; and cylinder 3 showed small cracks in the rubber boot and visible burn marks. These observations identify candidate contributors but do not establish which component failed first.

Table 2. Physical inspection of the ignition-coil assemblies

Cylinder 1 coil	**No visible physical damage**
Cylinder 2 coil	Light corrosion at the socket-pin area
Cylinder 3 coil	Small cracks in the rubber boot and visible burn marks

Table 3. Multimeter voltage observations at the ignition-coil connector

Component	**Positive supply (V)**	**IGT indication (V)**	**IGF indication (V)**	**Ground reference (V)**
Ignition coil 1	12	5	5	0
Ignition coil 2	12	Not detected	Not detected	0
Ignition coil 3	12	Not detected	Not detected	0

Electrical observations and measurement boundaries

The multimeter indicated a 12-V supply and 0-V ground reference at all three coil connectors. Approximately 5 V was indicated on the IGT and IGF lines for cylinder 1, whereas comparable indications were not detected for cylinders 2 and 3. Because the operating condition, loading state, repetition count, and sampling behavior were not retained, the values cannot be reproduced as a formal measurement protocol. They are interpreted only as asymmetric indications that justified further evaluation of the channels for cylinders 2 and 3; they do not identify the initiating fault.

Component substitution and DTC evidence

Replacement of the suspected ignition coils did not eliminate the reported vibration, misfire, reduced power, or increased fuel consumption, weakening the hypothesis that coil replacement alone would resolve the case. The original ECU did not yield readable DTC information with the available scan tool. After installation of a known-good ECU, the scanner displayed P0300, P0352, P0353, and P0171. These codes were observed only in the donor-ECU configuration;

the record did not preserve code status before clearing, whether codes were cleared, the operating interval before rescanning, freeze-frame data, live data, or fuel-trim values. The DTC evidence therefore indicates ongoing faults detected while the donor ECU was installed, not proof that the damaged original ECU stored the same codes.

Table 4. Diagnostic trouble codes displayed only during the known-good ECU configuration

DTC	Description	System	Scanner display	Local workshop priority
P0300	Random/multiple-cylinder misfire	Ignition	Displayed	Critical (local)
P0352	Ignition coil B primary/secondary circuit fault	Ignition	Displayed	Critical (local)
P0353	Ignition coil C primary/secondary circuit fault	Ignition	Displayed	Critical (local)
P0171	System too lean, Bank 1	Fuel	Displayed	High (local)

Table 5. Configuration-by-configuration diagnostic and claim-evidence matrix

Stage	Configuration/action	Principal observation	Interpretation	Reporting boundary
1	Original coils and ECU	Reported misfire, vibration, reduced power, and high fuel use; no readable DTC	Baseline trouble condition confirmed	Power and fuel use not quantified; baseline history incomplete
2	Coils 2 and 3 replaced	Symptoms persisted	Coil replacement alone was insufficient	Replacement duration and repeat count not retained
3	Known-good ECU installed and scanned	P0300, P0352, P0353, and P0171 displayed	Ongoing external circuit faults became reportable in the donor-ECU configuration	Compatibility, code clearing, run interval, freeze-frame, live data, and donor protection not retained
4	Original ECU and connector inspected	Visible damage along the ignition-driver path and degraded female contacts	Interconnected ECU-connector fault supported	Component designators, resistance, morphology, and direction of damage not established
5	Documented visible defects repaired or replaced	Continuity and stable workshop operation reported	Preliminary workshop functional restoration	Observation duration, drive cycle, repeated DTC scan, waveform, resistance, and durability not retained

Interpretation of substitution and DTC evidence

The donor-ECU test is diagnostically informative but is not equivalent to reading codes stored by the original ECU. The known-good ECU communicated with the scan tool and displayed P0352 and P0353, which align with the two channels for which comparable IGT/IGF indications were not detected; P0300 is consistent with the reported multi-cylinder misfire. P0171 is less specific. It may represent a concurrent air-fuel fault, a fuel-trim response during repeated misfire, or another unresolved condition. Because freeze-frame, fuel-trim, oxygen-sensor, and code-clearing data were not retained, the relationship of P0171 to the ignition fault cannot be determined. Modern misfire research similarly relies on standardized operating conditions and multiple signal streams rather than isolated observations (Abdelati et al., 2025). The evidence supports an ongoing circuit-level problem during the donor-ECU configuration, not proof that the original ECU stored or generated the same code set.

Connector and ECU-driver evidence

Visual inspection reported intact external harness insulation, undetected IGT/IGF indications for cylinders 2 and 3, degraded female contacts, and visible damage along the original ECU ignition-driver path. Connector studies show that fretting and imperfect crimp interfaces can destabilize resistance (Antler, 1985; Liu & Heaton, 2002; Swingler, 2000, 2009), while high-resistance connections can produce temperature rise under load and interacting degradation mechanisms can accelerate connector failure (Modi & Galgoci, 2020; Song et al., 2025). These findings make connector degradation a directly observed contributor and a plausible source of intermittent circuit behavior. They do not exclude a pre-existing ECU-driver fault, hidden harness intermittency, power/ground instability under dynamic load, moisture exposure, or prior repair. Because contact resistance, terminal force, dynamic voltage drop, temperature, oxide composition, and board-level electrical behavior were not measured, the direction between connector degradation and ECU damage remains unresolved.

Corrective work replaced degraded female contacts and repaired or replaced visibly damaged elements along the ECU ignition-driver path. The available record does not identify component designators, semiconductor type, terminal specification, crimp-tool model, conductor preparation, pull-force or crimp-height criteria, soldering parameters, cleaning method, dielectric treatment, or pre-energization electrical tests. The repair outcome therefore supports the general diagnostic logic but does not validate a reproducible remanufacturing procedure. The wording is intentionally limited to visible driver-path damage rather than a confirmed semiconductor failure mechanism.

Causal hypothesis and comparison with failure-analysis approaches

One possible sequence is abnormal coil or igniter switching, increased resistance or intermittency at degraded contacts, disruption of IGT/IGF control or feedback, and progressive stress along the ECU ignition-driver path. Ignition-system models and transient standards make this sequence technically plausible (ISO, 2011; SAE International, 2023; Stevenson et al., 2007; Yu et al., 2016), while connector studies support resistance instability and heating as possible contributors (Antler, 1981, 1985; Liu & Heaton, 2002; Modi & Galgoci, 2020; Swingler, 2000, 2009). However, FMEA, fault-tree analysis, and machine-diagnostic guidance require explicit separation of failure modes, evidence, assumptions, and competing branches (IEC, 2018; ISO, 2025; Vesely et al., 1981). Applying that principle here, the case demonstrates coexistence, configuration-dependent DTC visibility, and a repair response; it does not demonstrate time-resolved causation. The proposed sequence must therefore remain one evidence-informed hypothesis alongside pre-existing ECU damage, connector-first degradation, harness intermittency, power/ground instability, moisture/age effects, and prior repair.

Table 6. Alternative-cause assessment and causal boundaries

Candidate cause	Evidence in this case	Assessment	Remaining uncertainty
Abnormal coil/igniter switching	Physical coil damage, persistent circuit faults, and ECU driver-path damage	Plausible contributing cause	No transient waveform, peak voltage/current, or chronology
Connector corrosion or terminal relaxation	Visible degradation of female contacts; cylinder 2 socket-pin corrosion	Directly observed contributor	No contact-resistance, force, or material analysis
Harness intermittency	Visible cable condition reported as acceptable	Not strongly supported	No documented dynamic wiggle test or full continuity values
Power/ground instability	12-V supply and 0-V ground reference observed by multimeter	Partially screened	No dynamic voltage-drop test under load
Pre-existing ECU driver failure	Physical driver-path damage observed	Possible initiating or concurrent fault	Failure timing relative to coil and connector damage unknown
Moisture, age, or prior repair	Relevant history not available	Not assessed	Model year, odometer, exposure, and repair history missing

Post-repair verification

After correction of the documented visible defects, the workshop record reported restored continuity and stable engine operation. The observation period, idle duration, road-test or drive-cycle length, cold and hot restarts, repeat DTC scans, misfire counters, fuel trims, idle-speed variability, dynamic voltage drop, contact resistance, and oscilloscope confirmation were not retained. The defensible outcome is therefore preliminary workshop functional restoration during an unspecified observation period. The manuscript does not claim durable recovery of power, emissions, or fuel economy.

Practical and vocational-education implications

For workshop practice, the revised workflow recommends seven actions: document the baseline and instrument conditions; inspect power, ground, coils, connectors, and harness before replacement; interpret multimeter readings within bandwidth and loading limits; perform substitution only after compatibility and protection checks; record diagnostic trouble codes separately for each configuration and clearing state; repair only documented defects using a recorded procedure; and verify function with a defined drive cycle, repeated scans, and measurable acceptance criteria. These are proposed safeguards derived from the limitations of the present record, not procedures validated by this single case. For automotive vocational education, the case may be used as a learning resource for hypothesis generation, evidence evaluation, circuit tracing, diagnostic-trouble-code interpretation, stop criteria, and uncertainty reporting. This instructional use is consistent with evidence that diagnostic competence benefits from active problem solving and appropriately calibrated scaffolding (Chernikova et al., 2020; Hmelo-Silver, 2004), and with troubleshooting studies that emphasize coached practice and explicit representation of system states (Johnson et al., 1993; Lajoie & Lesgold, 1992). It also addresses the documented need to strengthen troubleshooting within engineering curricula (Fatokun & Gumbo, 2024). No pedagogical effectiveness or student competence gain was measured in this study.

Limitations

This study is limited to one Daihatsu Xenia 1.0 Non-VVT-i, one workshop, and one retrospective diagnostic record. It lacks a control vehicle, deliberately induced fault, repeated trials, pre-fault baseline, model year, odometer, full service and exposure history, complete instrument specifications, defined operating conditions, waveform/current measurements, connector-resistance and thermal measurements, dynamic voltage-drop testing, component-level semiconductor characterization, a documented DTC-clearing protocol, freeze-frame and live-data records, a specified repair protocol, and long-duration post-repair verification. Donor-ECU compatibility and safety controls were not retained. These limitations prevent statistical generalization and require the causal chronology to remain hypothetical. Removal of non-essential photographs and service-book diagrams also limits visual documentation but avoids unsupported publication-permission claims.

CONCLUSION

This evidence-classified single-vehicle case identified a consistent pattern: reported misfire and vibration; asymmetric multimeter indications on IGT/IGF channels 2 and 3; persistence of symptoms after coil replacement; P0300, P0352, P0353, and P0171 displayed only during the known-good ECU configuration; degraded female connector contacts; visible damage along the original ECU ignition-driver path; and preliminary workshop restoration after correction of documented defects. The convergent evidence supports treating the coil circuit, connector contacts, harness, and ECU driver as an interconnected diagnostic system rather than as isolated components. It does not establish the initiating component or a chronological cascade because waveform, current, resistance, thermal, component-level, and long-term verification data were unavailable. The principal scholarly contribution is a transparent method for distinguishing direct observation, diagnostically supported interpretation, and hypothesized mechanism in a complex workshop case. Future studies should use synchronized oscilloscope and current measurements, dynamic voltage-drop and contact-resistance tests, thermography, component-level analysis, configuration-controlled DTC logging, replicated vehicles, and defined drive-cycle verification. Educational research should separately test whether the revised case protocol improves diagnostic reasoning and safety competence.

REFERENCES

Abdelati, M. H., Mourad, M., Matar, A.-H., & Rabie, M. (2025). Enhanced engine misfire diagnosis through integration of vibration and acoustic emission signals using artificial neural networks. *Journal of Engineering and Applied Science, 72,* Article 137. https://doi.org/10.1186/s44147-025-00703-y

Adnyana, I. G. M., & Suyanto, W. (2013). Penggunaan EFI scanner sebagai media pembelajaran untuk meningkatkan minat, motivasi, dan prestasi belajar siswa. *Jurnal Pendidikan Vokasi, 3*(2), 192-209. https://doi.org/10.21831/jpv.v3i2.1601

Antler, M. (1981). Fretting corrosion of gold-plated connector contacts. *Wear, 74*(1), 27-50. https://doi.org/10.1016/0043-1648(81)90192-7

Antler, M. (1985). Electrical effects of fretting connector contact materials: A review. *Wear, 106*(1-3), 5-33. https://doi.org/10.1016/0043-1648(85)90101-2

Chernikova, O., Heitzmann, N., Fink, M. C., Timothy, V., Seidel, T., Fischer, F., & DFG Research Group COSIMA. (2020). Facilitating diagnostic competences in higher education: A meta-analysis in medical and teacher education. *Educational Psychology Review, 32*(1), 157-196. https://doi.org/10.1007/s10648-019-09492-2

Echsony, M. E., & Nurfaizin, K. (2018). Monitoring engine control unit (ECU) pada mesin Toyota Avanza 1300 cc menggunakan personal computer. *JEECAE (Journal of*

Electrical, Electronics, Control, and Automotive Engineering), 3(2), 183-188. https://doi.org/10.32486/jeecae.v3i2.263

Fatokun, J. O., & Gumbo, M. T. (2024). A narrative review of the criticality of problem-solving and troubleshooting skills for undergraduate students: The missing link in electronics engineering programmes. *Cogent Education, 11*(1), Article 2429868. https://doi.org/10.1080/2331186X.2024.2429868

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235-266. https://doi.org/10.1023/B:EDPR.0000034022.16470.f3

International Electrotechnical Commission. (2018). IEC 60812:2018 Failure modes and effects analysis (FMEA and FMECA).

International Organization for Standardization. (2011). ISO 7637-2:2011 Road vehicles - Electrical disturbances from conduction and coupling - Part 2: Electrical transient conduction along supply lines only.

International Organization for Standardization. (2025). ISO 13379-1:2025 Condition monitoring and diagnostics of machine systems - Data interpretation and diagnostics techniques - Part 1: General guidelines.

Johnson, S. D., Flesher, J. W., Jehng, J.-C. J., & Ferej, A. (1993). Enhancing electrical troubleshooting skills in a computer-coached practice environment. *Interactive Learning Environments, 3*(3), 199-214. https://doi.org/10.1080/1049482930030303

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development*, *48*(4), 63-85. https://doi.org/10.1007/BF02300500

Lajoie, S. P., & Lesgold, A. M. (1992). Dynamic assessment of proficiency for solving procedural knowledge tasks. *Educational Psychologist*, *27*(3), 365-384. https://doi.org/10.1207/s15326985ep2703_6

Liskiewicz, T. W., Kubiak, K. J., Mann, D. L., & Mathia, T. G. (2020). Analysis of surface roughness morphology with TRIZ methodology in automotive electrical contacts: Design against third-body fretting-corrosion. *Tribology International, 143*, Article 106019. https://doi.org/10.1016/j.triboint.2019.106019

Liu, D. R., & Heaton, C. E. (2002). Failure analysis of the electric crimp joint on a harness in an automotive environment (SAE Technical Paper No. 2002-01-1054). SAE International. https://doi.org/10.4271/2002-01-1054

Modi, M., & Galgoci, B. (2020). Evaluation of high resistance connection in automotive application. *SAE International Journal of Advances and Current Practices in Mobility, 2*(5), 2751-2759. https://doi.org/10.4271/2020-01-0926

Ridhuan, K., Handono, S. D., Asroni, A., Wahyudi, T. C., Irawan, D., Mafruddin, M., Budiyanto, E., & Nugroho, E. (2023). Pelatihan penggunaan scanner dan maintenance mobil injeksi untuk guru-guru SMK di Kota Metro. *Sinar Sang Surya: Jurnal Pusat Pengabdian kepada Masyarakat*, *7*(2). https://doi.org/10.24127/sss.v7i2.2779

SAE International. (2023). SAE J1113/11_202303: Immunity to conducted transients on power leads. https://doi.org/10.4271/J1113/11_202303

SAE International. (2025). SAE J2012_202509: Diagnostic trouble code definitions. https://doi.org/10.4271/J2012_202509

Song, J., Hilmert, D., & Kiel, F. (2025). Mechanisms of failure and state analysis of electrical connectors in automobiles. *Engineering Failure Analysis, 173*, Article 109427. https://doi.org/10.1016/j.engfailanal.2025.109427

Stevenson, R. C., Palma, R., Yang, C. S., Park, S. K., & Mi, C. (2007). Comprehensive modeling of automotive ignition systems (SAE Technical Paper No. 2007-01-1589). SAE International. https://doi.org/10.4271/2007-01-1589

Sukma, A. D., & Wailanduw, A. G. (2020). Rancang bangun trainer sistem pengapian engine stand Daihatsu menggunakan sistem ECU. *Jurnal Rekayasa Mesin, 6*(1), 7-12. https://doi.org/10.26740/jrm.v6i01.36960

Swingler, J. (2000). The automotive connector: The influence of powering and lubricating a fretting contact interface. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, *214*(6), 615-623. https://doi.org/10.1243/0954407001527484

Swingler, J. (2009). Enhancing connector reliability by using conducting polymer materials to minimise contact fretting. *Materials & Design, 30*(10), 3935-3942. https://doi.org/10.1016/j.matdes.2009.06.004

Vesely, W. E., Goldberg, F. F., Roberts, N. H., & Haasl, D. F. (1981). Fault tree handbook (NUREG-0492). U.S. Nuclear Regulatory Commission.

Yu, S., Tan, Q., Ives, M., Liu, M., Li, L., Chen, X., & Zheng, M. (2016). Parametric analysis of ignition circuit components on spark discharge characteristics (SAE Technical Paper No. 2016-01-1011). SAE International. https://doi.org/10.4271/2016-01-1011