Universal Library of Engineering Technology | Research Article

ISSN: 3064-996X | Volume 3, Issue 3

Open Access | PP: 75-81

DOI: https://doi.org/10.70315/uloap.ulete.2026.0303012

A Differential Pressure Sensor for Early Diagnosis of Progressive Intake Faults in Internal Combustion Engines: The IAHI Index

Edmond Gevorkyan

President, CODIAG, Nancy, France.

Abstract

Modern engine management compensates for many intake disturbances through closed-loop control, and partial clogging of the air filter leaves fuel consumption of a fuel-injected engine largely unchanged. The intake tract carries a broader range of progressive faults, including boost leaks, turbocharger degradation, fouling of the exhaust gas recirculation valve, coking of the intake manifold, and sensor drift. These faults raise fuel consumption and emissions, and they stay hidden until an onboard diagnostic code appears or a clear power loss develops. This work describes a small-range differential pressure sensor that measures the aerodynamic resistance of the intake path on a continuous basis and reduces that measurement to an Intake Aerodynamic Health Index, the IAHI. The purpose of the index is to enable early detection of intake faults that drive fuel and emission penalties, with filter replacement scheduling treated as a secondary use. A theoretical model built on relations among pressure drop, pumping power, and specific fuel consumption quantifies the direct pumping contribution and shows it to be small. A conditional sensitivity analysis estimates the potential energy and carbon impacts for the subset of vehicles that carry such faults, covering diesel, boosted, fleet, and heavy-duty applications. The sensor architecture, governing equations, modeling assumptions, conditional fleet sensitivity, study limitations, and a planned validation protocol form the body of the contribution. Every percentage stays a modeling assumption, and the index value derives from the resistance signature of an individual vehicle measured against its own healthy reference.

Keywords: *Intake Air, Differential Pressure, Aerodynamic Resistance, Condition-Based Maintenance, Fault Detection, Fuel Consumption, Emissions, Onboard Diagnostics.*

INTRODUCTION

The efficiency of an internal combustion engine depends on its capacity to draw the required air under controlled aerodynamic conditions. Electronic management already measures mass airflow with the MAF sensor, manifold pressure with the MAP sensor, intake air temperature, and, on boosted engines, boost pressure. These quantities serve as injection and emission controls, and they govern the torque the engine produces across its operating range. None of them returns a direct normalized measure of the total physical resistance of the intake path or of how that resistance drifts over time.

A distinction belongs at the start of any discussion of intake monitoring. In a modern feedback-controlled engine, a simple restriction in the air filter is compensated for by fuel regulation, and fuel consumption stays close to its baseline while peak power can fall. Filter replacement scheduling is not part of the value of an intake sensor. The value of such a sensor centers on early detection of a broader class of intake faults that includes boost leaks, turbocharger degradation, manifold and EGR coking, and sensor drift, all of which worsen combustion, consumption, and emissions, and all of which stay unseen until a fault code or a breakdown forces attention.

A blind window separates the moment when the intake is already restricted from the moment when a diagnostic code appears. Inside that window, no instrument reports the growing resistance, the driver feels at most a faint loss of pull, and a compression-ignition engine shows no idle hunting that might warn of trouble.

Citation: Edmond Gevorkyan, “A Differential Pressure Sensor for Early Diagnosis of Progressive Intake Faults in Internal Combustion Engines: The IAHI Index”, Universal Library of Engineering Technology, 2026; 3(3): 75-81. DOI: https://doi.org/10.70315/uloap.ulete.2026.0303012.

The goal of this work is a single sensor that provides the control unit with one additional piece of information: the total aerodynamic resistance of the intake, normalized to the IAHI index, suited for condition-based maintenance and predictive diagnostics. The sensor adds a measurement of the tract's physical state while leaving the MAF and MAP functions in place. The index ties to the healthy signature of a specific vehicle and serves as a trigger for early diagnosis before a progressive fault becomes irreversible.

BACKGROUND AND RELATED WORK

Intake restriction indicators have a long history on diesel engines, trucks, and off-road equipment. Their function remains narrow, since they signal when to change the air filter and leave the measurement disconnected from broader diagnosis. The reading marks a single component and reports nothing about the rest of the path.

Literature sets a boundary that this work accepts in full. An experimental study of compression-ignition engines shows that each 1 kPa increase in air filter pressure drop results in an average power decrease of 0.4 to 0.6% and a specific fuel consumption increase of 0.3 to 0.5%, with permissible filter resistance for passenger car engines ranging from 2.5 to 4.0 kPa (Dziubak & Karczewski, 2022a). A second study reports that the effect of air filter pressure drop on turbocharged engines stays small, since the boost system masks the restriction (Dziubak & Karczewski, 2022b). Laboratory testing of fuel-injected vehicles with closed-loop control confirms that clogging the air filter produces no measurable change in fuel economy, because the control system holds the target air-fuel ratio across the restriction (Synak et al., 2020). The filter restriction, by itself, fails as a fuel-consumption lever on a modern engine, and this conclusion shifts the purpose of an intake sensor toward the faults that matter.

Field practice on diesel engines reveals a recurring failure chain that motivates the present concept, and four linked observations describe it. The first observation concerns the pairing of faults at the moment of breakdown. A vehicle arrives with an airflow meter fault; the air filter shows heavy clogging in almost every case; and codes for the airflow meter, the EGR valve, and the coked manifold appear together, which separates the symptom from the cause. The second observation concerns the integrity of the maintenance record. Two causes drive clogging: a skipped service in which the service book still carries a replacement stamp with no replacement performed, and operation in a dusty environment, which allows the paper record to be falsified while the measured aerodynamic signature does not. The third observation concerns the environment, which is against the schedule. Operation in dust across fields, the plowing season, and the harvest season clogs the filter faster than any mileage interval allows, supporting maintenance driven by condition rather than a fixed interval. The fourth observation concerns irreversibility, and it carries the physical core of the argument. Even short driving with a dirty filter can lightly foul the EGR valve, preventing it from closing fully, and a self-sustaining cycle of manifold coking begins that narrows the cross-section and continues after the filter is replaced. Deposition of carbon on the walls of the EGR valve reduces the intake manifold's capacity and causes the valve to stick once the buildup exceeds a threshold (Woźniak et al., 2023). By the time a diagnostic code appears, the process has turned irreversible, and early closure of that window creates the value of the measurement.

Empirical testing of a modern diesel engine with electronic management follows the same path, as a filter contaminated after roughly 50,000 km of service increases fuel consumption and shifts the operating point away from the healthy reference (Dziubak et al., 2023). Onboard diagnostics responds to the consequence, the dead sensor, and stays blind to the cause, the rising intake resistance.

The proposed concept differs from a classical restriction indicator in three ways. It monitors the entire tract over the filter alone, transmits continuous, normalized information to the control unit or a diagnostic module, and converts differential pressure into a health index suited for drift warning and intervention planning.

The central hypothesis states that the aerodynamic resistance of the intake path, tracked continuously and normalized, serves as an early indicator of intake faults that can raise consumption and emissions before an OBD code or a noticeable power loss. The hypothesis rests on a physical chain in which an intake fault changes the pressure drop or its agreement with the expected flow; this deviation shifts the actual operating point away from a healthy reference, and combustion, boost, or regulation then operate in a less favorable zone. The effect remains minor on a healthy vehicle, but it becomes significant for the subset of vehicles that carry a real fault, with diesel, boosted, and heavy-duty service most exposed.

METHODS

Sensor Architecture

The system uses a small-range differential pressure sensor matched to the small pressure differences of the intake path. Two pressure tap points compare the inlet and outlet of a monitored zone, with the placement spanning from a point ahead of the filter to a point at the intake manifold, allowing the sensor to cover the entire tract. The signal travels as an analog output from 0.5 to 4.5 V or as a digital output over LIN, CAN, or a dedicated module. The control unit receives the pressure drop, corrects it for airflow, engine speed, temperature, and atmospheric pressure, and computes the IAHI index relative to the recorded healthy reference state. The architecture appears in Fig. 1.

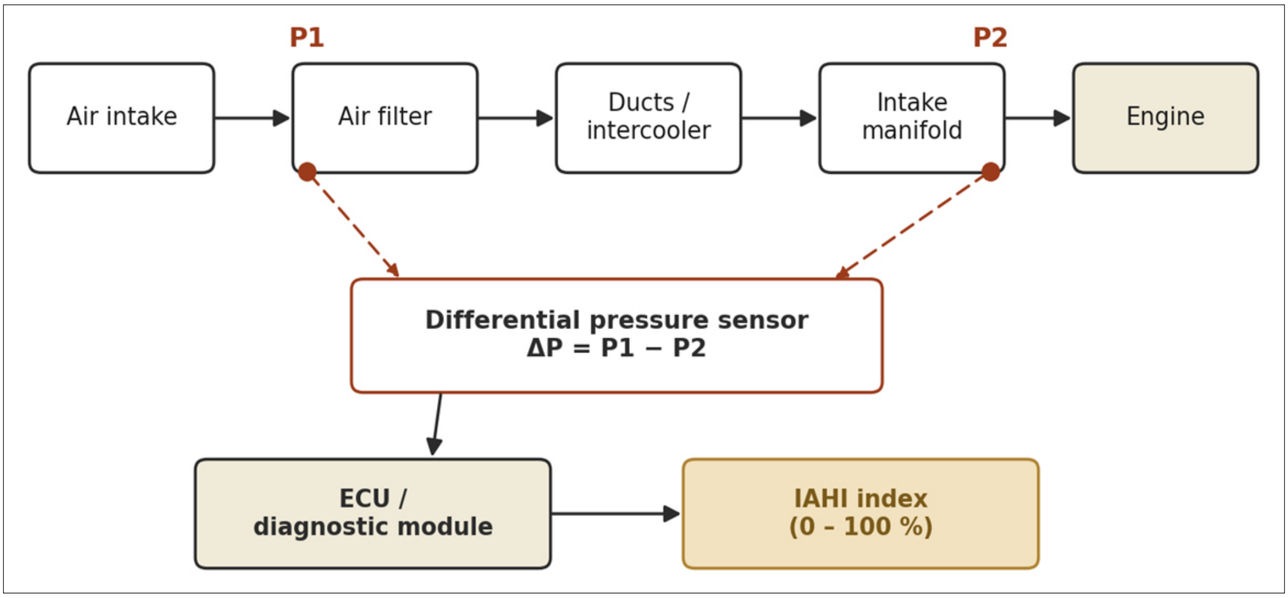

Fig. 1. Conceptual architecture of the intake aerodynamic-resistance sensor.

Theoretical Model

The pressure drop between the two points along the path follows from Equation 1, where P1 and P2 denote the two tap points.

$$\Delta P = P_1 - P_2 \quad (1)$$

A quadratic law for flow approximates the pressure drop in a given channel, as shown in Equation 2, where the air velocity v equals the volumetric flow Q divided by the effective cross-section A, ρ denotes the air density, and K represents the total resistance of the system.

$$\Delta P = K \cdot \frac{\rho}{2} \cdot v^2 \quad (2)$$

Clogging of the filter, the ducts, or the manifold, together with any fault that changes the flow, shifts the coefficient K. The pressure drop then rises for the same flow, and the relation departs from the healthy signature. The additional pumping power follows from Equation 3.

$$P_p = \Delta P_{add} \cdot Q \quad (3)$$

The additional theoretical fuel mass associated with this pumping is given by Equation 4, where ηe denotes the effective engine efficiency and PCI denotes the lower heating value of the fuel.

$$\dot{m}_{f,add} = \frac{P_p}{\eta_e \cdot PCI} \quad (4)$$

Equation 4 captures the direct pumping contribution alone, which stays small. The formulation separates it from the indirect effects of the fault, the worsened combustion, the load on the boost system, and the coked EGR path, which carry a significant share of the penalty once a fault exists.

Definition of the IAHI Index

The IAHI index provides a synthetic measure of the aerodynamic state of the intake, normalized against a healthy reference that combines a clean system, a new filter, and the pressure-drop-versus-flow signature established for the vehicle. Equation 5 gives the index, where the corrected reference pressure drop is divided by the corrected measured pressure drop and scaled by 100.

$$IAHI = 100 \times \frac{\Delta P_{ref,corr}}{\Delta P_{meas,corr}} \quad (5)$$

The index falls as the measured pressure drop deviates from the reference. A cap holds the value at or below 100%, and corrections for flow, temperature, and altitude are applied in the computation. The thresholds in Table 1 remain indicative and indicate deviation from the healthy state relative to any filter-replacement threshold.

Table 1. IAHI thresholds and recommended actions.

IAHI	Deviation from a healthy state	Recommended action
95 to 100%	Intake within norm	No action required
80 to 95%	Light drift	Observation
65 to 80%	Moderate deviation	Inspect the intake path
50 to 65%	Significant deviation	Diagnosis recommended
Below 50%	Marked anomaly	Intervention required

Modeling Assumptions

The computations that follow represent a theoretical model that checks the internal consistency of the relations and carry no experimental measurements. The adopted values match realistic orders of magnitude for a light diesel or a boosted gasoline engine at part load, the class where an intake fault produces a measurable effect. Table 2 lists the assumptions across three scenarios.

Table 2. Modeling assumptions across three scenarios.

Parameter	Low scenario	Medium scenario	Severe scenario
Air flow Q	120 m^3/h	180 m^3/h	240 m^3/h
ΔP healthy state	0.8 kPa	1.2 kPa	1.8 kPa
ΔP degraded state	2.0 kPa	4.0 kPa	7.0 kPa
Excess ΔP	1.2 kPa	2.8 kPa	5.2 kPa
Engine efficiency ηe	0.32	0.35	0.35
Fuel PCI	43 MJ/kg	43 MJ/kg	43 MJ/kg

The relationship between pressure drop and air flow for the healthy and degraded states is shown in Fig. 2, where the degraded curve indicates the increasing resistance of the whole tract across the air flow range of the three scenarios.

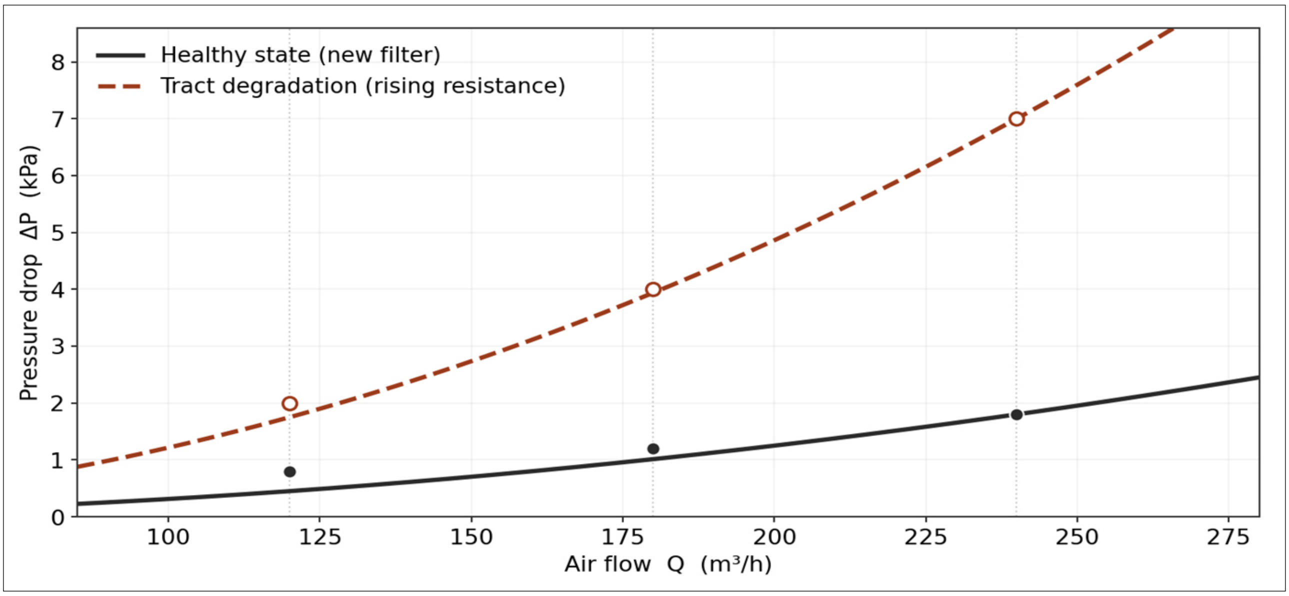

Fig. 2. Modeled pressure drop versus air flow for healthy and degraded intake states.

Planned Validation

Validation of the model calls for a protocol that compares the healthy state with controlled intake faults, including a moderate restriction, a severe restriction, a calibrated boost leak, and a partially blocked EGR path, as allowed by the test rig. Each test runs at a stabilized temperature on a repeatable route or a roller bench, with simultaneous recording of pressure drop, MAF, MAP, engine speed, calculated load, intake air temperature, atmospheric pressure, instantaneous consumption, and emissions where instrumentation permits. The recommended vehicles span a light-boosted diesel, a fuel-injected gasoline engine, and a diesel van across the 1,500-2,500 rpm range during transient phases. The protocol targets two checks: the first is that the IAHI index departs from the reference ahead of an OBD code, and the second is that this departure correlates with a measurable consumption or emission penalty once a real fault exists.

RESULTS

Calculated Over-Consumption

Table 3 presents the results under the preceding assumptions. The direct pumping column carries the energy needed to overcome the excess pressure drop alone. The correlated-fault column adds a penalty that reflects the combined effect of a real fault on combustion, boost, and engine management, and it applies only to vehicles that carry such a fault.

Table 3. Calculated over-consumption across the three scenarios.

Scenario	Q (m^3/h)	Excess ΔP (kPa)	Pp (W)	Direct fuel (L/h)	Direct pumping (%)	With fault (%)
Low	120	1.2	40.0	0.0125	0.27	0.9
Medium	180	2.8	140.0	0.0399	0.93	2.1
Severe	240	5.2	346.7	0.0987	2.31	3.9

The direct energy contribution of pumping remains moderate, and pumping alone cannot justify a significant gain. The significant share comes from the indirect effects of a real intake fault, and this is the share that the sensor detects early. The medium-correlated-fault scenario shows an overconsumption of 2.1% for the affected vehicle. The two contributions appear together in Fig. 3, where the gap between the two lines widens with the excess pressure drop.

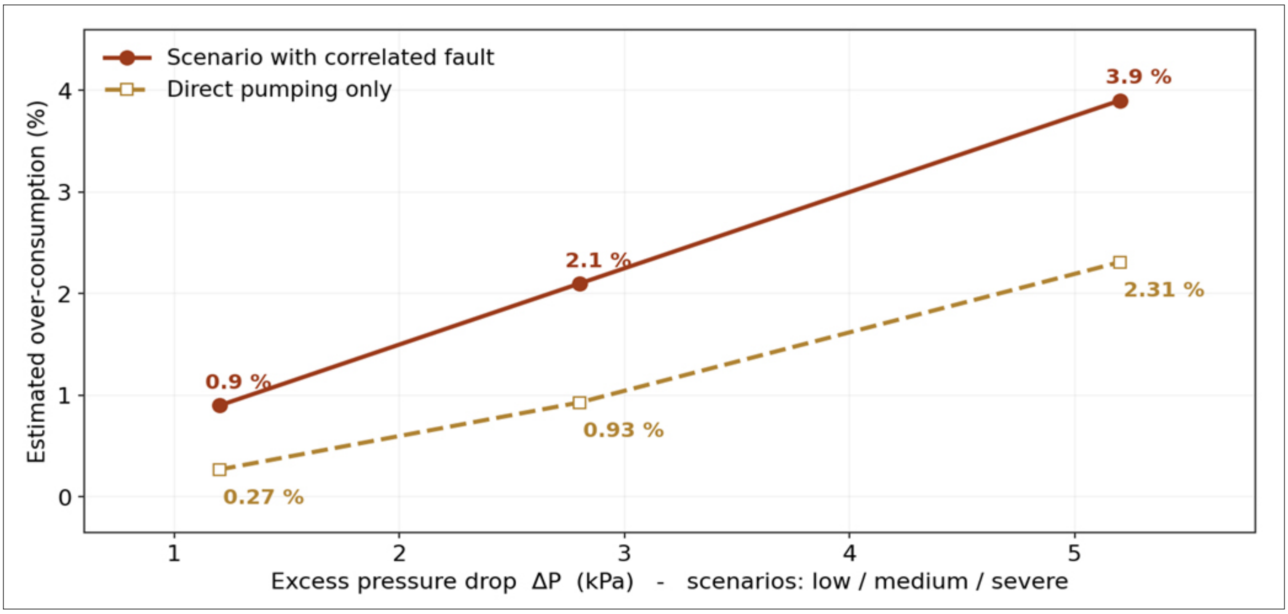

Fig. 3. Modeled over-consumption: direct pumping versus correlated-fault scenario.

Conditional Fleet Sensitivity

The energy and environmental interests rest on early correction of vehicles that carry a fault, and the analysis remains conditional. It estimates the impact for a subset of vehicles, given a given average overconsumption, that early detection would remove, with no claim that the whole fleet benefits. Table 4 lists the outcome across subset sizes from 5 to 100 million vehicles, with the carbon figure based on a modeling assumption of 2.5 kg of CO2 per liter of fuel.

Table 4. Conditional sensitivity by affected-subset size.

Affected subset	Use per vehicle	Removed over-consumption	Fuel saved	CO2 avoided
5 million	1,000 L/year	2%	0.1 billion L/year	0.25 Mt/year
10 million	1,000 L/year	2%	0.2 billion L/year	0.5 Mt/year
25 million	1,000 L/year	2%	0.5 billion L/year	1.25 Mt/year
50 million	1,000 L/year	2%	1.0 billion L/year	2.5 Mt/year
100 million	1,000 L/year	2%	2.0 billion L/year	5.0 Mt/year

The same conditional impact appears in Fig. 4, where the fuel saved and the carbon avoided scale with the size of the affected subset, and the rows mark different subset sizes of really faulty vehicles relative to the global fleet.

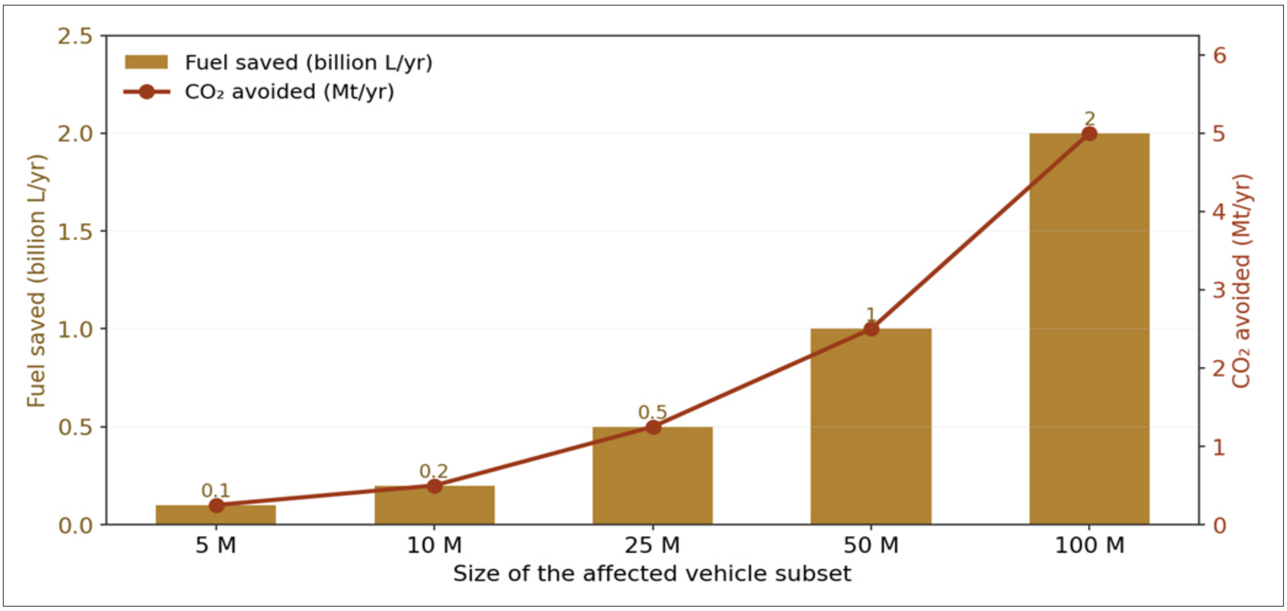

Fig. 4. Conditional sensitivity: impact of a 2% average gain by affected-subset size.

DISCUSSION

The direct pumping contribution stays small, and this outcome agrees with the experimental literature on filter restriction. The value of the measurement centers on early detection of the indirect effects of a real fault, the share that closes the blind window while it is still correctable.

An undetected intake fault can favor less complete combustion, raise soot formation on some diesel engines, and intensify coking of the EGR path and the manifold. The sensor surfaces the fault sooner, and timely intervention limits the buildup of deposits, protects the turbocharger, and shortens the time the engine runs in an undetected degraded mode. The durability gain comes from the new information the measurement supplies to the decision system, and an early trigger halts the irreversible coking cycle before it passes the point of no return.

The system can be integrated into original equipment or used as an external diagnostic module. The most fitting applications cover vehicles where an intake fault has a real effect, such as vans, delivery fleets, taxis, buses, agricultural machines, construction equipment, and diesel and boosted engines under heavy use or in dusty environments. The IAHI data can be sent to a telematics platform, and maintenance can then start from the actual state of the intake rather than a single mileage figure. Dust drives clogging faster than any mileage interval, which makes condition-based monitoring preferable to schedule-based monitoring for fleets in such service. Predictive maintenance in the automotive sector draws on condition-monitoring data, such as pressure readings, to estimate remaining useful life and schedule maintenance actions (Arena et al., 2022).

The contribution rests on the systemic use of a known measurement rather than differential pressure alone, since the method converts that measurement into a normalized intake health index, ties it to the reference signature of a specific vehicle, and uses it as a trigger for early diagnosis rather than a simple filter signal. A gas-path approach to turbocharger health offers a precedent, since it defines dimensionless flow-capacity and efficiency indices that characterize component health from measurable path parameters (Cui et al., 2018). As far as the author is aware, the literature carries no normalized intake-resistance index of this kind tied to an individual healthy signature. The positioning aligns with the shift in automotive maintenance toward condition-based logic, and it accepts the boundary set by the literature. The filter restriction, by itself, fails as a consumption lever on a modern engine, which directs the indicator toward the faults that matter.

The present study forms a theoretical model. The reported percentages lack experimental status and extend to no whole fleet. In a modern feedback-controlled engine, a healthy vehicle experiences no intake-related overconsumption, since the energy gain remains conditional on a real fault and its correction. The link between intake state and consumption depends on the engine type, the boost system, the EGR strategy, the management approach, the driving style, and the environment. Sensor drift in the differential element can bias the index, and the correction scheme must separate a true intake deviation from an instrument artifact, a concern that parallels the analysis of mass air flow sensor faults on diesel engines (Akal & Selvi, 2023; Helali et al., 2025). The model calls for calibration using real measurements to quantify the IAHI index's early-detection capacity.

CONCLUSION

This work describes a sensor for intake aerodynamic resistance combined with a numerical health index, with the purpose of early diagnosis of intake faults rather than scheduling filter replacement. The model confirms that the direct pumping contribution remains small and that the index's value rests on its ability to surface faults that worsen consumption and emissions while the faults remain correctable. The conditional sensitivity analysis shows that for the subset of affected vehicles, the diesel, boosted, fleet, and heavy-duty cases, early correction can deliver a measurable fuel saving and an emission reduction at scale. The concept ties the measurement to the healthy signature of a specific vehicle and places the reading at the center of a condition-based decision process that closes the blind spot between actual intake restriction and the appearance of a diagnostic code. The concept merits a structured experimental validation, and the planned protocol sets the path toward that quantification.

REFERENCES

1. Akal, D., & Selvi, İ. (2023). Effects of clogged air filter on power, torque, fuel consumption and emissions of diesel engines in tractors. *Petroleum Science and Technology, 41*(24), 2419–2433. https://doi.org/10.1080/10916466.2023.2230248
2. Arena, F., Collotta, M., Luca, L., Ruggieri, M., & Termine, F. G. (2022). Predictive maintenance in the automotive sector: A literature review. *Mathematical and Computational Applications, 27*(1), 2. https://doi.org/10.3390/mca27010002
3. Cui, X., Yang, C., Serrano, J. R., & Shi, M. (2018). A performance degradation evaluation method for a turbocharger in a diesel engine. *Royal Society Open Science, 5*(11), Article 181093. https://doi.org/10.1098/rsos.181093
4. Dziubak, T., & Karczewski, M. (2022a). Experimental study of the effect of air filter pressure drop on internal combustion engine performance. *Energies, 15*(9), Article 3285. https://doi.org/10.3390/en15093285
5. Dziubak, T., & Karczewski, M. (2022b). Experimental studies of the effect of air filter pressure drop on the composition and emission changes of a compression ignition internal combustion engine. *Energies, 15*(13), Article 4815. https://doi.org/10.3390/en15134815
6. Dziubak, T., Karczewski, M., & Dziobek, I. (2023). Empirical study of the effect of the air filter on the performance and exhaust emissions of a diesel engine. *Combustion Engines, 193*(2), 94–111. https://doi.org/10.19206/CE-161881
7. Helali, A., Belkacem, I., Abdellaoui, J., & Zegnani, A. (2025). Vibration analysis for diagnosis of diesel engines with air flow sensor failure. *Technologies, 13*(9), Article 380. https://doi.org/10.3390/technologies13090380
8. Synák, F., Kalašová, A., & Synák, J. (2020). Air filter and selected vehicle characteristics. *Sustainability, 12*(22), Article 9326. https://doi.org/10.3390/su12229326
9. Woźniak, M., Siczek, K., Zakrzewski, S., Just, P., Ozuna, G., & Onescu, C. (2023). Deposition effect of carbon deposits on charge flow in EGR valve equipped CI engine. *Combustion Engines, 192*(1), 26–35. https://doi.org/10.19206/CE-150503