Design and Implementation of an IUMPR Data Collection System in Automotive Applications

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ABSTRACT

The article presents the solution developed by ATS, called IUMPR Reader, created to meet the requirements of the legislation. This regulation requires the continuous and accurate collection of IUMPR data in light vehicles. The initial challenge involved the development of hardware capable of connecting to the vehicle's OBD-II port, aiming to reliably collect critical data. During the prototyping phase, extensive technical tests and adjustments were carried out, ensuring both the accuracy of the measurements and the robustness of the system in real conditions.

Later, a communication architecture was developed using 4G connectivity and the MQTT protocol, allowing the secure and real-time transmission of data to an AWS-based infrastructure. Data processing takes advantage of advanced IoT services, scalable storage and computational analysis, culminating in the implementation of an interactive dashboard in Power BI that offers detailed visualizations and predictive diagnostics. Extensive field testing and simulations were essential to optimize the integration between hardware and software, while the use of agile methodologies enabled continuous refinements based on technical feedback, ensuring constant evolution of the solution.

INTRODUCTION

The development of automotive technology has been significantly influenced by increasingly stringent emissions legislation over the past few decades. Technological advances in engine control strategies, like as improved fuel injection systems and precise air–fuel ratio regulation, have not only enhanced performance and fuel economy but also enabled more efficient control of emissions. Simultaneously, aftertreatment systems, including catalytic converters, diesel particulate filters, and selective catalytic reduction technologies, have evolved to meet the lower emissions thresholds imposed by environmental regulations.

These systems, while highly effective in reducing the pollutants generated, introduce complex dependencies that require a sophisticated monitoring approach to ensure that they perform optimally in real-world operating conditions, creating both opportunities and challenges in the field of diagnostics. That way the OBD (On-Board Diagnostics) systems have transformed from simple fault detection tools into intricate systems designed for real-time diagnostics and performance evaluation, ensuring that every critical component works harmoniously to meet stringent regulatory and performance standards.

Despite the progress, gaps still exist. Some vehicle components can be continuously monitored by the OBD system, while others require specific conditions for reliable diagnostic results. Therefore, one potential gap is the disparity between laboratory testing and on-road performance. Real-world conditions can pose challenges that are not fully captured during traditional compliance testing. Sensor drift, environmental variability, and aging components all contribute to discrepancies between laboratory and real-world results. These gaps have led to the development of additional performance metrics for OBD systems, such as the "In-Use Monitor Performance Ratio (IUMPR or IUPR)".

The IUMPR is designed to evaluate the effectiveness and reliability of various OBD monitors during normal vehicle operation. It provides a dynamic measure of system health and compliance. The motivation behind IUMPR is to better capture on-road variability, thereby allowing for more responsive maintenance decisions and regulatory interventions. The metric supports continuous improvement in engine management strategies, ensuring that both emission reductions and engine performance targets are met.

While IUMPR brings numerous benefits, its full implementation faces several challenges, including the substantial need to collect and process large volumes of operational data. This data is essential to accurately compile monitor operational statistics and fully capture real-world performance variations, thus requiring significant investment in advanced data collection and analysis technology.

The best and most reliable source for this operational data is the vehicle fleet itself. In the case of Brazil, for example, these are vehicles that comply with Proconve L7 and L8. According to the latest vehicle emissions report available by CETESB, the circulating fleet until 2023 in São Paulo state presents the following evolution:

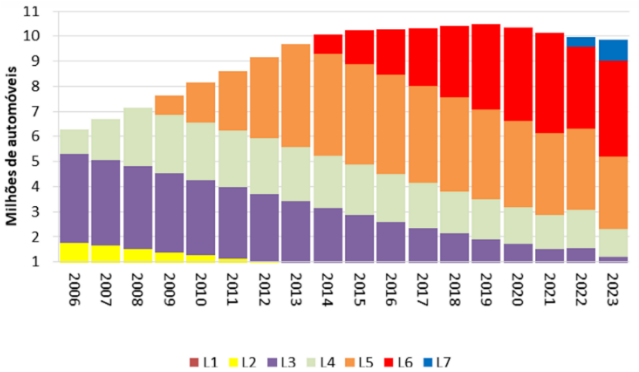

Figure 1. Gasoline Passenger Cars Fleet in Sao Paulo State (2023) [1]

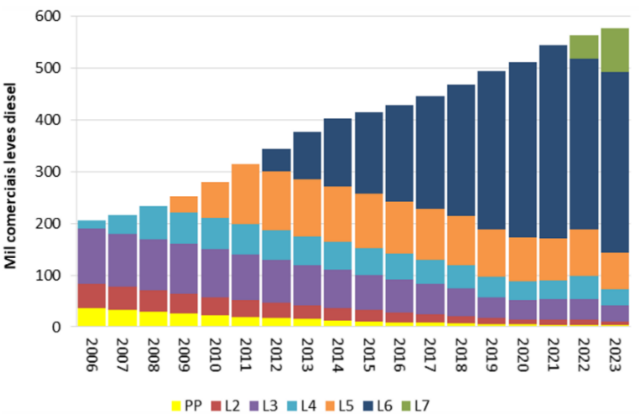

Figure 2. Diesel Light Commercial Vehicles Fleet in Sao Paulo State (2023) [1]

There are several possible solutions for collecting fleet data, which is why this topic is currently under discussion between the AEA OBD technical committee and IBAMA. The objective of this work is to define the best approach for collecting IUMPR data throughout the useful life of vehicles.

A robust and integrative approach is needed to ensure compliance with legal requirements regarding IUMPR minimums. In addition, it also encourages technological innovation and transparency in environmental control processes, promoting benefits for the automotive sector as well as for air quality and public health.

IUMPR: LEGISLATION OVERVIEW

In 2005, CARB introduced the “In-Use Monitor Performance Ratio (IUMPR or IUPR)” concept into the OBDII standard, which was subsequently introduced in 2011 into the Euro 5b+ (EOBD) standard [2]. In Brazil, the concept of IUMPR came with the introduction of Proconve L7 and L8 phases [3]. IUMPR can be defined as the ratio of how many times a specific monitor is enabled during vehicle operation:

$$IUMPR = \frac{Numerator}{Denominator}$$

Numerator: is a counter that measures the number of times the vehicle has been operated in such a way that all the conditions necessary for a specific monitor to detect a fault have been met.

Denominator: counter indicating the number of events in which the vehicle was operated under special conditions for each specific monitor. Vehicle operating conditions for denominator increment:

- Cumulative time since engine start greater than or equal to 600 seconds.
- Cumulative vehicle operation at or above 40 km/h occurs for 300 seconds or more.
- Continuous operation of the vehicle at idle for 30 seconds or more.
- Altitude of less than 2440 m.
- Ambient temperature higher than or equal to -7°C.

The OBDBr-3 system must inform, in addition to the counter of ignition cycles and the general denominator, the numerators and denominators for the following monitors (if applicable):

- Catalysts.
- Exhaust gas sensors.
- Evaporative emission control system.
- EGR system.
- VVT system.
- Secondary air system.
- Particulate matter filter.
- NOx aftertreatment system with NOx adsorber.
- NOx aftertreatment system with catalyst / liquid reagent.
- Boost pressure control system.
- Fuel supply system for compression-ignition engines (PL8 vehicles).

The IUMPR data must be reported in accordance with ISO 15031-5.

It is also important to mention some differences between the PL7 and PL8 standards regarding the monitoring of IUMPRs:

- For PL7, there is no mandatory minimum rate, IUMPR values are informative only.

- For PL8, IUMPR values must be greater than 0.1 for all monitors and more than 50% of all vehicles have an IUMPR average greater than or equal to the minimum value applicable to the monitor.

A point still open in the standard and which is one of the motivations for this work is that, according to the normative instruction 23 from September 24th, 2020, item 7.1.7.: “For confirmation of compliance with the conditions of item 7.1.6, the program that comprises the form of data collection, the target fleet, the sampling frequency and the control method will be defined in a specific IBAMA regulation.”

The methodology that will be implemented for this data collection is currently under discussion in the AEA working groups and inspection agents. Although nothing has been officially published yet, some guidelines are already being strongly considered, including:

- Segmentation of data collection by macro-regions (Midwest, North, Northeast, South, and Southeast), allowing for more detailed analyses and regional adaptations.

- Send a report with the fleet's IUMPR data to the competent government agency from 2026 onwards.

IUMPR READER OVERVIEW

In order to meet the demands of current legislation and to consider upcoming needs (still under discussion in related working groups) regarding the collection, compilation and provision of IUMPR data for the passenger vehicle fleet and diesel LCVs, a system was developed with the following requirements:

- Easy to operate, there is no need for many steps between connecting to the vehicle, collecting and sending data.

- Ability to collect data from a large fleet in the shortest possible time. One of the possible ways to collect fleet data is to collect it when the customer leaves their vehicle at the dealership to, for example, carry out preventive maintenance. Developing a product as a dealership tool allows the automaker to receive IUMPR data related to its products more efficiently and quickly and thus perform more efficient analyses, as the data can be sent directly to the responsible area within the automaker (production conformity, homologation, OBD calibration, etc.).

- Information about the location where the collection was carried out. This data can be obtained via GNSS.

- Connectivity for sending data to the cloud.

- Data security, only authorized users can access the collected data.

- Secure cloud storage.

- Pre-processing of data before making it available to the end user, facilitating their analysis. For example, separating data from diesel applications from data from Otto applications, or even, in addition to collecting the numerator and denominator data, also calculating the final rate for each IUMPR.

- Tool for preparing reports, whether for internal use by the manufacturer or even for sending to a government agency.

The figure below briefly illustrates the IUMPR collection process used for the IUMPR Reader solution presented in this material, from the collection itself to the provision to the end user and the reports.

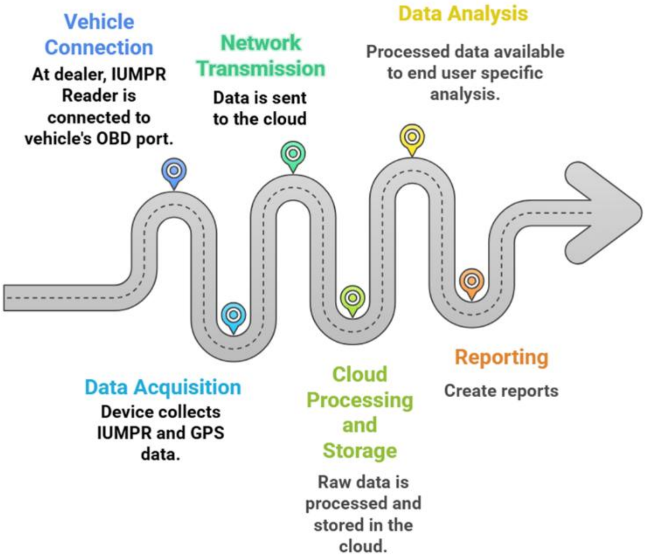

Figure 3. IUMPR data collection roadmap

With this roadmap in mind, the solution was developed considering three major functional blocks:

- Equipment: includes the hardware and the embedded software for its operation. The main components include CAN communication, connection to the 4G network, connection to the GNSS (Global Navigation Satellite System) and internal memory.

- Cloud: pre-processing of collected data and secure cloud storage.

- Analysis and reporting: tool that allows the end user to access data stored in the cloud for analysis (dashboard) and report creation.

The figure below summarizes the components of the developed solution.

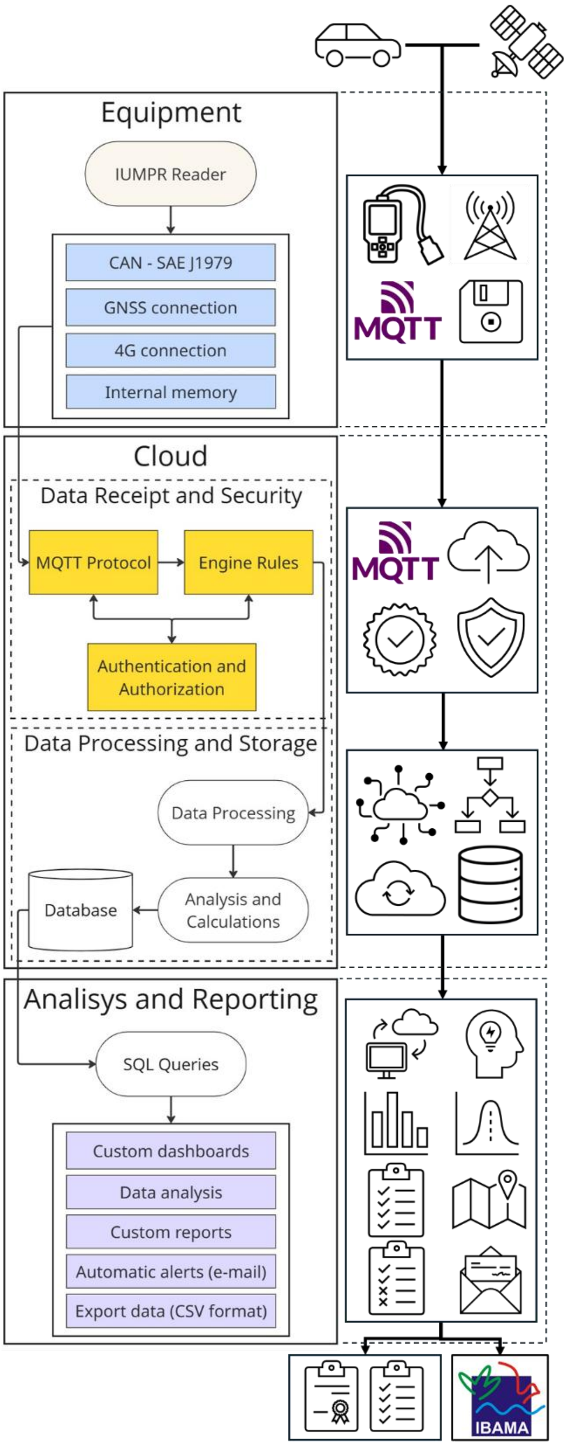

Figure 4. Functional blocks of the IUMPR Reader solution

In the next chapters, each of these functional blocks will be discussed in more detail.

As inputs to the IUMPR Reader solution, we have data from the passenger vehicle fleet and diesel LVCs and location data obtained through GNSS. Power BI can generate customized reports with the analysis of IUMPR data, but it is the responsibility of the automaker to send the report to competent government agencies.

IUMPR READER: EQUIPMENT

The main function of the IUMPR Reader is to collect vehicle data and, for this purpose, the equipment can communicate with the vehicle's CAN network through the OBD port. Information regarding the OBDBr-3 system is made available on the CAN and is reported, in accordance with Normative Instruction 20, in accordance with ISO 15031-5.

ISO 15031-5:2015 is intended to satisfy the data reporting requirements of On-Board Diagnostic (OBD) regulations in the United States and Europe and any other region that may adopt similar requirements in the future. It specifies message formats for request and response messages, timing requirements between request messages from external test equipment and response messages from vehicles and between those messages and subsequent request messages, behavior of both the vehicle and external test equipment if data are not available, and a set of diagnostic services, with corresponding content of request and response messages, to satisfy OBD regulations. ISO 15031-5:2015 references SAE J1979-DA, which includes all definitions of PIDs, OBDMIDs, TIDs, and INFOTYPEs.

IUMPR data is available in Service $09 (Request Vehicle Information) [4]. Within this service, the IUMPRs are separated between spark ignition engines and compression ignition engines, each containing information from specific monitors for each application.

In-use Performance Tracking for spark ignition engines:

- OBD Monitoring Conditions Encountered Counts (general denominator).

- Ignition Cycle Counter.

- Catalyst Monitor Completion.

- Oxygen Sensor Monitor.

- EGR and/or VVT Monitor.

- AIR Monitor.

- EVAP Monitor.

- Secondary Oxygen Sensor Monitor.
- Air Fuel Ratio Imbalance Monitor.
- Particulate Filter Monitor.

In-use Performance Tracking for compression ignition engines:

- OBD Monitoring Conditions Encountered Counts (general denominator).
- Ignition Cycle Counter.
- NMHC Catalyst Monitor.
- NOx/SCR Catalyst Monitor.
- NOx Adsorber Monitor.
- PM Filter Monitor.
- Exhaust Gas Sensor Monitor.
- EGR and/or VVT Monitor.
- Boost Pressure Monitor.
- Fuel Monitor.

For each monitor, the numerator and denominator information are available, as well bank 1 and bank 2 if applicable.

In addition to IUMPR information, other information is also collected, such as Vehicle Identification Number (VIN), mileage, Calibration IDs, and the status of the MIL at the time of collection. This information will also be made available to the end user.

Since the IUMPR data will be presented by macro region, it is necessary to obtain the data from the location where the collection was made. To do this, the equipment can obtain location data using the GNSS (Global Navigation Satellite System). The system can use data from different GNSS systems (GPS, GLONASS, Galileo and BeiDou) to obtain the position more accurately.

Once the vehicle data and position data have been collected, they must be sent to the cloud. In the current version of the equipment, data transmission is performed via a connection to the 4G network. The board used for this 4G connection already has an OCD certification. The OCD is the legally constituted technical institution that, by delegation of Anatel (National Telecommunications Agency), conducts conformity assessment processes for telecommunications products, this certification is one of the regulatory approvals that telecommunications equipment must obtain in Brazil before being marketed and used [5]. In essence, this certification attests that a product complies with the technical and regulatory requirements set by Anatel. The certification process confirms that the equipment meets all relevant technical standards, covering aspects such as performance, electromagnetic compatibility, and safety.

Data is transmitted to cloud using the MQTT (Message Queuing Telemetry Transport) protocol. MQTT is a lightweight, publish-subscribe network protocol designed for efficient communication in environments with limited bandwidth, high latency, or unreliable networks. It was originally developed for monitoring oil pipelines over satellite connections, but its low overhead and simplicity have made it a popular choice for Internet of Things (IoT) applications [6]. One of its key characteristics is the Publish-Subscribe Model. Instead of establishing a direct connection between a sender (publisher) and a receiver (subscriber), MQTT uses a central intermediary called a "broker." Publishers send messages to topics on the broker, and subscribers receive messages by subscribing to those topics. This decoupling makes the system more scalable and flexible. It is also lightweight and efficient, MQTT's minimal protocol overhead means that even devices with limited processing power, memory, or battery life can use it effectively. This efficiency is critical in IoT scenarios where network resources might be constrained.

Security considerations related to the use of MQTT implementations typically incorporate security measures such as authentication, TLS/SSL encryption, and access control to ensure that data is protected during transmission.

Follow an image of the current version of the equipment.

Figure 5. IUMPR Reader equipment

In addition, the equipment also has a touch-sensitive LCD display to facilitate data collection operations and to allow the operator to track the progress of data collection and submission.

Internal memory is also available, so when it is not possible to connect to AWS, for example due to lack of 4G signal, the vehicle data is stored in memory for later sending.

IUMPR READER: CLOUD

This block includes the reception of data sent by the equipment, through the MQTT protocol and 4G connection. Here is the system's security layer, cloud storage, processing of the sent message and provision of formatted data for later analysis and reports. All these resources are present in Amazon Web Services (AWS).

AWS is a comprehensive and widely adopted cloud computing platform provided by Amazon. It offers a vast collection of services and solutions to help organizations move faster, lower IT costs, and scale applications. It provides on-demand cloud computing resources over the internet. Instead of maintaining physical servers and data centers, organizations can rent computing power, storage, and other services from AWS as needed. With its global infrastructure, AWS operates data centers in various regions around the world. This global footprint ensures high availability, low latency, and redundancy in case of failures. The architecture is designed to offer robust disaster recovery capabilities and business continuity.

For the development of the IUMPR Reader solution, one of the most important requirements of the project was to ensure that all collected data was protected against any misuse, unauthorized access, loss, theft or unauthorized disclosure. AWS offers a secure environment with multiple layers of security for its physical infrastructure, network, and virtualization. They comply with numerous global security standards and certifications, so, choosing AWS for this functional block proved to be the most complete solution.

This functional block of the IUMPR Reader solution can be divided into two other smaller blocks: AWS IoT Core and AWS Services.

The first of these, AWS IoT Core, provides cloud services that connect the IoT device (IUMPR Reader equipment) to the AWS cloud services.

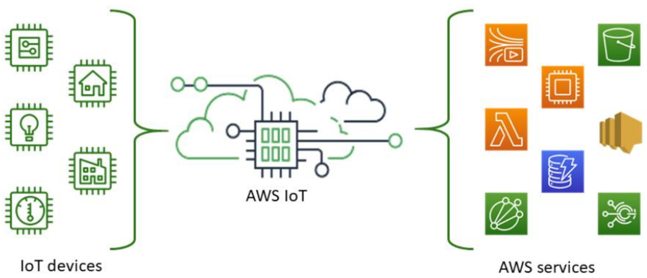

Figure 6. AWS IoT Core [7]

AWS IoT uses a robust authentication and authorization model to ensure that only trusted devices can communicate with their services. Here's an overview of the certification and authorization structure for connecting a device to AWS:

- Device Authentication via X.509 Certificates: The X.509 the International Telecommunication Union (ITU) defines certificate standard [8], this body established the foundational framework for the certificates used to authenticate identities and establish secure communications. An X.509 certificate is a digital document that uses the X.509 public key infrastructure (PKI) standard to bind a public key with a specific identity. These certificates are widely used in networks, websites (via SSL/TLS), and various cryptographic protocols to ensure secure data communication and authentication.

- AWS IoT requires devices to prove their identity during connection by using X.509 certificates, these certificates are either generated by AWS IoT or issued by a trusted Certificate Authority (CA) whose root certificate has been registered with AWS IoT, that way when a device connects, both the device and AWS IoT authenticate each other using their respective certificates.

- Certificate Registration and Management: devices are registered with AWS IoT by associating the certificate with an AWS IoT "thing" (a digital representation of the physical device), these certificates can be created, rotated, and revoked using AWS IoT's certificate management capabilities.

Once the authorization and authentication of the equipment has been guaranteed, the next step is to process the data received.

Data from devices is securely ingested and stored. Once the upload is completed, an event notification is triggered. This event-driven model is crucial for real-time processing, allowing data transformations or validations immediately after data ingestion. At this point, the raw data sent by the equipment is divided and tabulated according to the type of application (spark ignition engines or compression ignition engines), and each of the IUMPR rates is also calculated according to the respective numerators and denominators.

AWS provides a fully managed Extract, Transform, and Load (ETL) environment. It can transform raw data into a consumption-ready format. ETL tasks maintain a centralized Data Catalog, ensuring data consistency and ease of access. With the processed data now available and its schema cataloged, the next step is to enable querying of the data, enabling more complete data analysis.

While the AWS Services are used in the background to prepare and manage the data. Power BI can connect directly to AWS data catalog to run SQL queries. This setup allows the end user to create interactive reports and dashboards based on your up-to-date, AWS-managed database.

IUMPR READER: ANALYSIS AND REPORTING

The last functional block of the IUMPR Reader solution contains the dashboards for end-user analysis. This layer was developed using Microsoft Power BI.

Microsoft Power BI [9] is a business analytics service by Microsoft that provides interactive visualizations and business intelligence capabilities with an interface simple enough for end users to create their own reports and dashboards. With an extensive library of visualization types (charts, graphs, maps, tables, etc.), Power BI lets users create interactive, dynamic reports, allowing users to drill down into data details, filter results, and pivot views based on their needs.

Power BI provides robust security features including row-level security, which ensures that users can only see data specific to their role, and comprehensive data governance policies that align with compliance standards.

By using AWS services as a data source that Power BI can access, it was possible to develop a solution for creating interactive reports and dashboards with cloud-based data.

With the IUMPR data collected from the vehicle and the dashboards created in Power BI, it is possible to check the ratio of each of the IUMPRs quickly and easily, also allowing you to view the data individually for a specific VIN or even consolidated for a set of VINs.

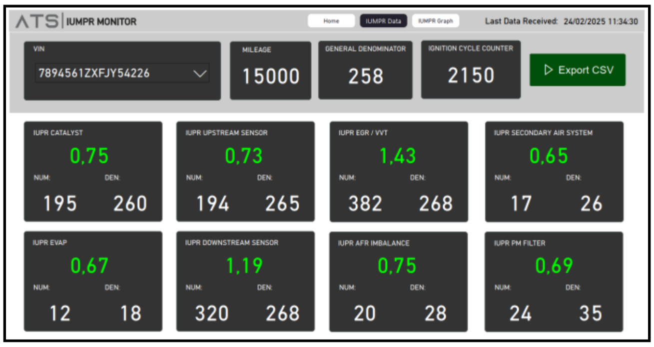

Figure 7. Dashboard with IUMPR performance data

As the database grows over time, where data from a specific VIN may have been collected more than once, for example every 10,000 km during the vehicle's periodic review, it is possible to monitor the evolution of the IUMPR performance data, making the analysis even more complete.

Figure 8. Dashboard with the evolution of IUMPR performance data throughout the useful life of the vehicle

With location information also available in the cloud, it is possible to display the distribution of collection locations directly on the map. This data is important for consolidating IUMPR data by region.

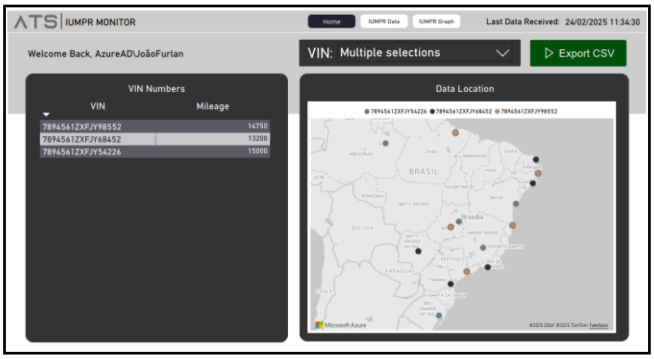

Figure 9. Dashboard with the location of IUMPR data collections

With all this information available and using Power BI it is possible to generate tailored reports for environmental audits, internal analysis, and regulatory compliance, simplifying data sharing and decision-making.

Additionally, the tool allows the end user to receive instant notifications via email or dashboard for regulatory non-compliance, ensuring proactive issue management.

CONCLUSION

The traditional OBD system, while foundational, has limitations in capturing the full spectrum of on-road variability. This gap necessitates the implementation of metrics like the In-Use Monitor Performance Ratio (IUMPR), which provides a dynamic measure of how effectively and reliably OBD monitors operate during normal vehicle use. It underscores the challenge automakers face in reliably collecting and processing the vast volumes of real-world operational data necessary to accurately calculate and report IUMPR values across diverse vehicle fleets. This challenge is further complicated by the need to align with evolving regulatory requirements and reporting methodologies currently under discussion.

In response to these demands, the article presents the IUMPR Reader solution developed by ATS. This comprehensive system integrates specialized hardware for efficient data collection directly from vehicle OBD-II ports, capturing critical IUMPR counters, VIN, mileage, and location data via GNSS. The solution employs a robust communication architecture utilizing 4G connectivity and the lightweight MQTT protocol for secure and real-time data transmission to a scalable cloud infrastructure built on Amazon Web Services (AWS).

The AWS-based cloud component is central to the solution's effectiveness, providing secure data ingestion via AWS IoT Core, durable storage, automated processing and cataloging capabilities through AWS Services. This ensures that raw data is transformed and organized into a format ready for analysis. The final layer, powered by Microsoft Power BI, offers interactive dashboards for detailed visualization, analysis of IUMPR performance over time and across regions, and the generation of necessary reports for internal use or submission to regulatory agencies like IBAMA.

Ultimately, the IUMPR Reader solution provides a practical, scalable, and secure framework for automakers to meet the stringent IUMPR data collection and reporting requirements. By automating data flow from vehicle to analysis, it not only facilitates compliance with current and anticipated regulations but also empowers manufacturers with valuable, data-driven insights to optimize vehicle performance, enhance diagnostic strategies, and contribute to improved environmental control and air quality.

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ABBREVIATIONS

AEA: Associação Brasileira de Engenharia Automotiva
AWS: Amazon Web Services
CARB: California Air Resources Board
CETESB: Companhia Ambiental do Estado de São Paulo
ETL: Extract, Transform, and Load
IBAMA: Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis
IoT: Internet of Things
IUMPR: In-Use Performance Ratio
LCV: Light Commercial Vehicle
MQTT: Message Queuing Telemetry Transport
OBD: On-Board Diagnostics
OCD: Organismo de Certificação Designado
PID: Parameter Identification
PKI: Public Key Infrastructure
PROCONVE: Programa de Controle de Emissões Veiculares
SAE: Society of Automotive Engineers
VIN: Vehicle Identification Number