Remote Validation during vehicle development phase: higher project reliability and better usage of validation vehicles through big data analysis

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ABSTRACT

During vehicle development and validation phases, data acquisition of Engine Control Unit and external sensors signals is common pain point for engineers and technicians responsible to evaluate automotive systems (e.g., Fuel Injection Equipment, FIE, and After Treatment Systems, ATS), and often it is not possible to cover all vehicle working conditions. This could lead to future field problems and, ultimately, extra costs for manufacturers and suppliers.

The usage of off the shelf dataloggers in validation vehicles for an extended time can directly solve the issue to cover all working conditions. Unfortunately, the higher the number of validation data to be evaluated, the longer the time required to manually analyze this data, and a solution that integrates the benefits of dataloggers and accounts for this issue must be created.

Remote Validation is described as the continuous flow of time-based data from validation fleet with automated evaluation of relevant signals, and it aims to have more efficient and effective validation activities of systems, components, and their software functions. Using a 2022 Off Highway application in the Latin American market this paper details this novel approach, its challenges, and its expected and extra benefits when compared to traditional validation activities.

INTRODUCTION

Data validation is one of the challenges the automotive industry faces during the development phase. Automobile manufacturers ensure quality and safety by conducting tests in real-life conditions. Therefore, the field test time should cover all possible operating conditions of the vehicle during its entire service life.

Due to the numerous variants of vehicles, sometimes this step is not financially feasible since each configuration would demand tests. In this context, regardless of the particularities of each project, it is crucial to recognize the impracticality of covering all possible operating conditions, resulting in the possibility of future problems, such as component failures, warranty claims, engineering rework, vehicle recalls, and, consequently, additional costs for the manufacturer and its suppliers.

A possible solution is to adopt Remote Validation, which allows real-time data collection and analysis. This approach provides faster and more accurate information on the vehicle's performance, resulting in important insights into its behavior. By using this method, car manufacturers are able to decrease the time and costs associated with real-life testing since the data collection will be done through a datalogger, for an extended period of time, and no technical personal would be required to stay in the vehicles during the tests.

Real-time analysis of the collected data provides a deeper understanding of the vehicle's performance and a higher error detection due to the extended data collection time and the higher number of monitored vehicles. Therefore, the method presents a continuous improvement of the application since the greater the volume of data received, the better the understanding of the system behavior.

TRADITIONAL VALIDATION OF AUTOMOTIVE COMPONENTS, SYSTEMS, AND FUNCTIONS

The validation of automotive components (fuel injector, rail, high pressure fuel pump), systems, and their software functions - and for the purpose of the discussion in this paper, specifically the ones used as part of Fuel Injection Equipment (FIE) in diesel vehicles - often follows the industry standard of collecting real data from the Engine Control Unit (ECU) and external sensors from inside the vehicle using a laptop and dedicated data acquisition software. This approach has been used in the automotive industry for decades and to function well one person operates the vehicle while another is responsible for the data acquisition tasks. The activities done in this fashion will be referred to in this paper as the “traditional validation”. The “optimization” of this process by reducing the activities to only one person simultaneously responsible for the two activities is dangerous, it is not allowed by road safety legislations and must be always avoided.

Each validation test done following this traditional approach takes around one week of work inside the vehicles. The amount of data collected varies depending on the vehicle type (on road vehicle, off road machinery), vehicle variants in the project, weather conditions (especially important for agricultural machines), and vehicle availability to perform the needed maneuvers for the tests. In an ideal scenario, each supplier would have the vehicle exclusively available for their validation activities and without overlapping tasks. However, in a more real situation, the vehicle is shared with different suppliers and has also to perform other activities not related to any tests (e.g., harvesting according to farmers will instead of the tests requirements, mileage accumulation for durability purposes). This usually leads to a common scenario in which it is not cost effective to run the validation tests in each vehicle variant possible in the project and is not possible to cover all possible vehicle working conditions.

As a tentative to find a compromise, during the test’s definition to be performed in the development and validation phases of each project, the critical operation - also referred to as “worst case operation” - and the most critical applications - the vehicles to be tested - are defined between the OEM and the supplier. With this definition, the tests will be performed only in the agreed vehicles and the other applications will be validated automatically. This approach is very useful, but it does not consider specific situations that could occur in some vehicle variants which will not be tested.

Given these constraints, the vehicle time is limited and must be used in the best way possible, and it makes necessary to have an engineer or technician inside the vehicle to instruct the driver on the maneuvers to perform. Although the test responsible inside the vehicle is observing its behavior in real time, the effort to make calibration changes during the tests is not of great value and the downtime between measurements is used for a more detailed evaluation and preparation of calibration fixes to be used in the next vehicle activity. After the data is collected in the field, the work is finished in the following weeks when the test responsible will analyze the bulk data and will create a report for the OEM with the final evaluation releasing or failing the application of the tested component, system, or function.

Even though this validation approach has been used consistently it has some limitations and having more time in the vehicles and more data available to observe all possible working scenarios would be beneficial. However, the more data available the more time needed to analyze it as depicted in Figure 1 below.

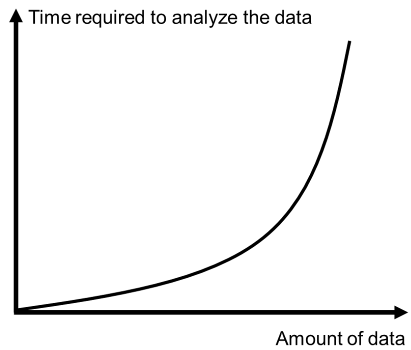

Figure 1. Amount of data vs. time required for analysis

REMOTE VALIDATION

Remote Validation can be described as the continuous flow of time-based data from validation fleet with automated evaluation of relevant signals and it aims to have more efficient and effective validation activities of systems (FIE, ATS), components (fuel injector, rail, high pressure fuel pump), and their software functions. It emerged as a possible solution to the problem introduced in the previous section of the limitations to analyze a large amount of data.

This validation approach has been used in Europe and was successfully used to validate a tractor application for the

Latin American market in a 2022 project. Although Remote Validation can be used in any vehicle development project where the technical requirements for the datalogger installation are met, an assessment of the project maturity must be done before deciding to only apply this validation method. The assessment done for this tractor justify its choice as the pilot project in Latin America: the project motivation was an ECU update due to component phase out; no significant changes in the FIE layout; overall project change was classified as light/super light considering physical and calibration differences; and, emission legislation Proconve MAR-I [1] which have broader emission limits when compared to On Highway legislations.

After the technical evaluation from the system engineering department, it was defined that the validation tests required to release this application were a Rail Pressure Governor (RPG) check and a Rail Pressure Monitoring (RPM) check. During an RPG check the actual fuel pressure inside the diesel common rail is checked against the calibrated map and the deviations between the two curves must be inside internal Robert Bosch tolerances. Calibration changes are required should any deviations above thresholds are identified during the tests During an RPM check the FIE system is monitored and in case any hydraulic error happens calibration or physical changes are required to fix a faulty scenario.

As explained in the previous sections, this validation when done in the traditional way would happen over the course of 2 weeks resulting in approximately 10 hours of measurements in the vehicle and only running specific maneuvers to reproduce the worst-case operation. Conversely, by using the datalogger and the Remote Validation approach it was possible to record over the course of 3 months more than 250 hours worth of measurements with the actual load collectives in the components enabling a more accurate understanding of the system behaviour under realistic operation.

These benefits became evident when the customer needed an extra evaluation aside from the RPM and RPG checks that were agreed in the beginning of the project. The fuel high pressure pump inlet temperature needed to be assessed to better understand its behaviour during the tractor maneuvers as this temperature was approved as “border line” in the previous application. As this signal was available at the Controller Area Network (CAN) bus and both the datalogger hardware and software have the flexibility to remotely change the signals recorded, no extra trip to the vehicle location was required to change the recording parameters. Prior to the Remote Validation in the tractor the customer defined the “Operation Mode B” as the worst-case operation for the fuel temperature at the pump inlet; however, with the real data it was possible to see that the worst-case operation is in fact the “Operation Mode A” as presented in Figure 2.

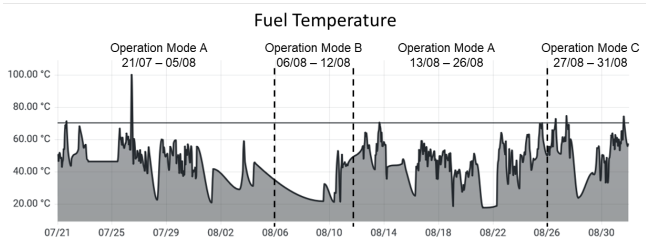

Figure 2. High pressure pump inlet temperature

DATA ACQUISITION

The Remote Validation method uses a device that records the ECU data through Controller Area Network Universal Measurement and Calibration Protocol (CAN XCP) [2], ingests the data into a cloud computing service through the mobile network to then be processed and later be presented in a dashboard to the domain experts. This so-called data pipeline is shown in Figure 3. The cloud computing system is also able to show the unprocessed signals on a web page interface in near real time.

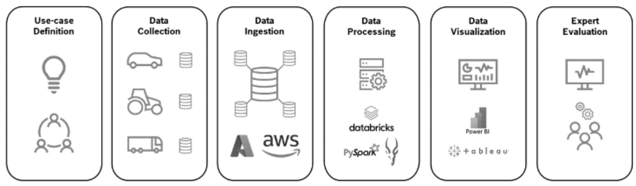

Figure 3. Data pipeline

The datalogger used in this project communicates with both CAN XCP and SAE J1939 [3] protocols and can be easily installed in the vehicle due to its standard OBD connector present in every vehicle being released in the market. The near real time monitoring feature makes it possible to visualize the vehicle’s current location, most important signals and it also sends alerts if any signal surpasses a configurable threshold. The device saves the recorded data locally, transfers it to a cloud service and then deletes it from the internal memory to prevent memory overload. Whenever the mobile network is unavailable the device’s internal memory (expandable with a micro-SD card) makes it possible to locally store several hours of measurements (up to a month), which will then be transferred to the cloud when internet connection is back.

The hardware operates with a voltage between 9V and 36V and it is possible to use the vehicle’s battery as power supply. The datalogger software can also be updated remotely whenever needed, making this process faster and more reliable. The solution has also high flexibility and scalability once the measured signals can be changed remotely at any time and the recording configuration can be replicated into a whole fleet.

During the usage of the datalogger in the project some problems happened, and they needed to be solved as quickly as possible to assure the validation success. Since the collected data will be the input for the development and validation engineering analysis the data collection must happen with less interference as possible. For future reference, and not limited to them, some problems are:

- Correct CAN port with the relevant signals cannot be easily accessible in the vehicle.

- Software updates that have not yet been tested and are not guaranteed to be application neutral (plug and play without any problems).

- Physical connections problems such as wiring harness short circuit, wiring harness breakage, wrong resistance value.

- Minor changes or differences of the electrical layout in the vehicles making it impossible to replicate the communication across the vehicle fleet.

DATA ANALYSIS

Manually analyzing the bigger amount of data collected with the usage of a datalogger for the Remote Validation approach is neither efficient nor feasible, and to overcome this challenge a big data approach is used as also done in [4]. The raw vehicle data is transferred to a cluster (e.g.: Databricks [5], Apache Hadoop [6]) because of the process power needed since the recorded measurements are defined in time series with a time sample of approximately 10 milliseconds.

Each validation test (for this project RPG check, RPM check and fuel pump inlet temperature evaluation) needs a code and a visualization and each pair of code and visualization represents a so-called use case. Each use case could have different signals lists and to improve efficiency in the processing time only the needed signals are loaded.

The data uploaded in the cluster needs to be processed and the state-of-the-art tools used in this step are Python [7] and the Apache Spark [8] framework (usually through PySpark which is a Python API for Apache Spark). The output of the code is a data frame saved and then accessed with a data visualization tool and the state-of-the-art software for this step is Tableau [9]. Tableau makes it is possible to create a variety of dashboards addressing the requirements of the engineer or technician responsible for the analysis. Tableau dashboards are reliable and can also be published online and accessible via a web interface, reducing the cost of local licenses and the need to install another software in the computers of the test responsible. Another possibility of visualization tool is Grafana [10]. Even though Grafana has simpler plot capabilities, it is particularly useful for near real time monitoring and signal timeline observations.

These dashboards are the final product used internally for the engineers and technicians responsible for the technical evaluation and they need to be easily accessible with a relatively low loading time. The possibility to create automated reports only with the important data is also of great interest and it is being studied internally.

CONCLUSION

When compared to the traditional validation approach, Remote Validation stands out due to the speed in which the data is available in the dashboards (near real time), the possibility to process the raw data and present valuable insights to aid in the technical evaluation, and the flexibility of the datalogger hardware and software to change the recorded variables remotely. As it is common in most pilot projects it was expected to have a steep learning curve with many procedures not yet in the desired maturity state to be reproduced in the future next projects. The feedback from all parties involved in the field tests and data analysis activities (suppliers, OEMs, technical personal) is especially important in this pilot phase to better tailor the process to deliver what is expected from this novel approach.

Unfortunately, not all projects are suitable to be validated remotely and assessments of the technical feasibility and the project maturity must be done before deciding which validation method will be done in the project to guarantee a successful validation. The technical limitations, often related to the compatibility of the communication protocol available in the vehicle and in the datalogger, tend to be overcome naturally as old vehicles are being updated with more recent ECUs. In fact, there is an upcoming window of opportunity to spread the use of Remote Validation in Off Highway vehicles that will be updated following the MAR-2 emission legislation in the Brazilian market in the upcoming years.

It is important to highlight that the Remote Validation and the use cases (PySpark code and Tableau dashboards) do not aim to replace the work done by the system engineering department, the goal is to serve as aid for a better, safer, and more reliable validation.

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