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openZDM

# OPEN PLATFORM FOR REALIZING ZERO DEFECTS IN CYBER PHYSICAL MANUFACTURING

## Testbeds final implementation & Lessons learned

| | |
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| Abstract | This document provides an overview of the testbed's integration in openZDM pilots. The deliverable reports and demonstrates the progress in demonstration status for project proposed solutions. |
| Keywords | Key assets, Minimum Viable Product, TRL, improvement indicators. |
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# Table of Contents

## List of Figures



## List of Tables



## List of Abbreviations & Acronyms

| | | |
|---|---|---|
| AAS | : | Asset Administration Shell |
| DAT | : | Data Analytics Tool |
| DST | : | Decision Support Tool |
| DT | : | Digital Twin |
| DTT | : | Digital Twin Toolset |
| JSON-LD | : | JavaScript Object Notation for Linked Data |
| KPI | : | Key Performance Indicator |
| MQTT | : | Message Queue Telemetry Transport |
| NDI | : | Non-destructive inspection |
| PoC | : | Proof of concept |
| RA | : | Reference Architecture |
| SoM | : | System on Module |
| TRL | : | Technology Readiness Level |
| WP | : | Work Package |

# Executive Summary

This document aims to present a summarized and public version of the openZDM project results. The content of this public deliverable is organized as follows:

**Section 1. Project introduction and overall results:** This document presents the final status from the implementation of advanced Non Destructive Inspections (NDIs) developed in WP3 (full list of openZDM NDIs in Appendix I) within openZDM platforms' services developed in WP4 to serve pilot requirements, including the customization required to adapt those to the characteristics of each company. Section 1 presents a table as a summary of the **main assets and services** used and their evolution along the project, covering the milestones in M18th, M24th and finally, M42th.

**Sections 2 to 6: Summary of the Use Cases Achievements:** These sections detail the five pilots of the project. Each pilot section is organised in a general overview, key assets evolution and demonstrator proofs, aligned with the KPIs proposed in the project proposal. Main achievements were: **VDLWEW** successfully tested in line new five NDI based on in line x-ray, laser line triangulation and artificial vision instruments (NDI#1, NDI#2, NDI#3, NDI#4 and NDI#6). Additionally, VDLWEW, LMS and AIMEN lead the use of openZDM services by developing AAS type 2 and Product AAS type 3, operative with the NDIs AAS. Data driven models are operative in the openZDM platform (complete list of quality assessment modules or DATs available in Appendix II). DT functionalities and business layers are fully operative on premises, and openZDM platform components have been used as well from the cloud. **VWAE** successfully integrated the laser triangulation system G3F (NDI#8) mainly in the final assembly line, with some of them tested as well in the Body Shop, and one was integrated in a robot, with data successfully flowing to the openZDM platform and visualised by dashboards. All AAS required are fully developed, as well as a detailed DT, type 3 AAS and 2 data models. The main challenge was the prediction of data between two different zones of the plant (body shop and final assembly). OpenZDM platform components have been deployed locally on the VWAE server. **SONAE's** pilot was focused on developing digital services around the AAS standard, standardisation and data models use. The result of the project was the testing of the defect detection and recipe recommendations. A novel dashboard to prioritise the key information for the operators and use of the dashboard itself, as well as the overall statistics of the project, was tested in line.

**VIDRALA** achieved an AI model capable of estimating the thickness of the bottle (in three control points), fully operative within the openZDM platform in Elton's plant. Digital twin is fed with real-time process data, and it is fully operative. Composer tool has been validated, and openZDM platform components in the cloud have been successfully implemented. Finally, **APTIV** successfully implemented two NDIs based on artificial vision (NDI#10 and NDI#11) in line, increasing the TRL of the Cassandra system. With improved infrastructure, communications and with the training of data-driven quality modules, a detection near to 99 % of the welding defects has been achieved. It is worth highlighting that novel NDI#10 has been used in the industrial line for more than a year and improvements in the hardware, regarding refrigeration, better location and improved data based has been fed back and improved.

**Section 6: Lessons Learned**. This section summarises the main lessons that each of the pilot leaders wanted to highlight.

# 1 Introduction

Zero-defect manufacturing is a mandatory practice in European manufacturing. Europe is aligned with no-waste fabrication and optimised production, where cost is minimised while maximizing quality. This parading requires novel approaches and mature enabling technologies, where new online non-destructive inspection (NDI) could be communicated efficiently in the line. The ability for both the line and the broader value chain to promptly react to this information is paramount.

The main goal of WP5 was to deploy and demonstrate the openZDM solutions in five industrial pilot lines at the respective industrial facilities. OpenZDM provided a platform with a set of integrated applications to enable proactive quality assessment and control towards zero-defect manufacturing and reduced waste in Manufacturing. For the pilot's implementations, it was required to integrate, customise project developments with the guidance of the respective end user & pilot leader, focusing on the deployment, validation, and demonstration of each industrial pilot line.

OpenZDM pilots were 5: **VDLWEW** (Trailing arm production process demonstrator), **VWAE** (Vehicle body shop and final assembly demonstrator), **SONAE ARAUCO** (Wood board manufacturing demonstrator), **VIDRALA** (bottle manufacturing demonstrator) and **APTIV** (Battery production use case).

## 1.1 Overall Evaluation

Evolution in the pilot's implementation was supported by the increasing capabilities in the Minimum Valuable Products (MVP) used along the project. MVPs developed in WP3 and WP4 were the base for WP5 Proof of concepts, preliminary testbench and final implementations, due to their orchestration in WP5 pilot demonstrations. The specification of main achievements is summarised below in Table 1.

**Table 1: Project Objectives and specific activities progress in pilot demonstrations.**

| Objective number | Title | Specific activities presented in M18 demonstrations | Specific activities presented in the M24 demonstrations | Final Activities in M42 demonstrations |
|---|---|---|---|---|
| Obj 1 | **To develop and deploy an open platform based on RAMI4.0 and AAS standards.**<br>1. The platform will support at least deployment over the cloud and hybrid (partially on-premises and partially on the cloud.<br>2. Allow for at least 8 users, with different workflows, preserving data isolation as of the final version.<br>3. The time from the data creation in the sensor/NDI connected to the platform until the storage to the physical layer of the platform max 4.9 sec. | AAS type 2 for operative NDIs (VDLWEW, VWAE, VIDRALA). | Completed AAS type 2 for all the use cases, except for AAS for NDI9b due to missing data. | Completed all AAS type two for all the use cases. AAS for NDIs and products are implemented and available in the openZDM platform. |
| | | AAS for product (VDLWEW, APTIV) | All AAS for products are defined and in two cases already updated (VWAE, updated for VDLWEW, updated for APTIV, VIDRALA batch-based, SONAE) | AAS type 3 has been implemented for VDLWEW and VWAE.<br>The platform supports local on-premise deployment, hybrid deployment, and cloud deployment. |
| | | AAS for partial process (VDLWEW, VWAE, SONAE ARAUCO, APTIV) | AAS for SONAE has been preliminary compared with AAS in the openZDM platform. The openZDM solution had a better performance, in msec. | A test was carried out to validate that 8 users, in parallel with different workflows, can work with the platform.<br>The time from data creation until stored in the database of the platform was measured to be on average 1.4 seconds. The maximum time observed was 30.6 |

| Objective number | Title | Specific activities presented in M18 demonstrations | Specific activities presented in the M24 demonstrations | Final Activities in M42 demonstrations |
|---|---|---|---|---|
| | | | | seconds, with values over 4.9 seconds representing 0.01% of the value set. |
| Obj 2 | To develop and deploy Digital Twins for online process evaluation and adaptation.<br>1. Digital twins were successfully used in at least 3 use cases.<br>2. over 75% Ratio of false overall quality assessment evaluations of data-driven analytics, fed by the twin models.<br>3. Digital twin update with live data of at least 3 sources in less than 1.5 sec. | Partial DT implementations for all the pilots. Partial integration within openZDM platform. | Progress on DT implementations for all the pilots. Integration within openZDM platform. | Functional DT are implemented and tested in all 5 pilots. Update with live data takes at most 899 ms. |
| | | | Digital twin tool set tested the 2D visualization environment for VDLWEW and APTIV use cases. | The configurator was tested in four pilots, demonstrating the standardisation and availability of data-driven models and analytic tools in the platform. |
| | | | The configurator has been tested with VIDRALAs use case. | All DTs are now operating with live data, enabling real-time monitoring and providing new information that enhances the platform's analytical capabilities. The DT also enables simulations, provides 2D/3D visualisation for easier deviation detection, and contributes to reducing rework, operator verification time, the number of products requiring alignment, and overall production costs. It is important to highlight that data (not available before openZDM) is being collected as storage, and it is being used, and will be used to improve data models. |
| Obj 3 | To define AI-based Data-driven quality assessment approaches.<br>1. at least 1 data-driven tool will be | First models for expert systems or quality modules from data-driven approaches are | Extensive production of preliminary models for the data analytics tool. | In SONAE, defect prediction (DAT#3 was tested online) and DAT#5 have been tested to check the |

| Objective number | Title | Specific activities presented in M18 demonstrations | Specific activities presented in the M24 demonstrations | Final Activities in M42 demonstrations |
|---|---|---|---|---|
| | developed and validated for each use case that are not presented at the moment in their production line | implemented in VWAE, VIDRALA, SONAE ARAUCO and APTIV. | | model's accuracy prediction. |
| | | | Data-driven approaches were improved in VWAE, VDLWEW, SONAE ARAUCO and APTIV. | In VWAE, the predictive model tested between the body shop and final assembly showed promising results for some target points. |
| | | | In VDLWEW, the model predicts the dimensional metrics of Width, Thickness, Straightness over Thickness, Straightness over Width. | In VDLWEV, DAT#0 for dimensional product predictions, DAT#1 for process parameters recommendation and DAT#2 for environmental impact calculation are implemented. |
| | | | In VIDRALA's thickness prediction have been possible to achieve a model estimation of defective bottles. Additional data to corroborate these findings is needed | In VIDRALA, data models are providing promising early defect prediction, being the NDI#9 model presented for patent.<br>In APTIV, the image processes allow a 99% defect detection of missing welds. |
| Obj 4 | **To develop and integrate NDISs for zero defects**<br>1. at least 1 NDI technique will be developed and validated for each of the use cases that are not present at the moment in their production line.<br>2. At least 3 different sensors will be acquired for each use cases along their production line and their data fully integrated in the Data Model. | **11** NDIs spanning 3 technologies implemented: Vision-based, laser line triangulation-based, and X-ray inspection-based. In certain instances, these NDIs were integrated into the production line, while in other cases, the design of NDIs has been finalized, and comprehensive laboratory testing was conducted. | Overall **twelve** Non-Destructive Inspections (NDIs) spanning three distinct technologies have been implemented in four use cases (VWAE, VDLWEV, VIDRALA, APTIV): Vision-based, laser line triangulation-based, and X-ray inspection-based. In APTIV, the Cassandra system has been used in line and currently improvements are being carried out to increase its TRL. | All the NDIs are being used in line, except for NDI7. However, the X-ray NDIs (NDI#0/7) in VDLWEV are not integrated, but available offline. |

| Objective number | Title | Specific activities presented in M18 demonstrations | Specific activities presented in the M24 demonstrations | Final Activities in M42 demonstrations |
|---|---|---|---|---|
| Obj 5 | **To test & validate the integrated solution to the pilots (demonstrating TRL7) on ZDM.**<br>1 5 different industrial pilot scenarios (in Portugal, Italy, Spain and Netherlands)<br>2 -20% compared to production lines without any advanced ZDM strategy implemented. | Demonstrations with the first integration from assets, services and openZDM platform using real data from pilots are presented. | Improvements in M24 demonstrations from the first integration of assets, services and openZDM platform using real data from pilots are presented.<br>In all pilots was achieved DT visualization in openZDM platform. | Real-time data has been used for demonstrators. All pilots have a local installation of the openZDM platform.<br><br>All use cases report the benefits of having new data available from their plants and how it is providing them with new insights about their processes. |
| Other objectives | • Contribution to standards for ZDM<br>• Skills development for ZDM<br>• AAS Type 3 implementation *(new)* | Even if further discussed during online and presential meetings, no conclusion is presented. | Several discussions regarding suggested ontology (i.e. OPC_UA) and the proposal to use the properties of the VDI/VDE/VDMA 2632 for machine vision based NDIs (VDLWEW NDI#2, NDI#3 and NDI#6, VIDRALA NDI#9a) have been started. | AIMEN is part of the standardization group for AAS. Their main contribution in the frame of openZDM was: Active participation in the creation of CWA:18230 Zero Defects Manufacturing – Basic Principles and Requirements.<br>Proposal for the standardization of properties related to Machine Vision Systems in ECLASS, allowing for the standardized description of these devices (pending release).<br>AAS type 3 is operative in VDLWEW and VWAE use cases. |

# 2 Trailing arm production process demonstrator (VDLWEW)

## 2.1 Overview

The VDLWEW use case was focused on processing metal bars to produce trailing arms for trailers, trucks and buses. The main objective in the use case was to provide a set of tools, to achieve proactive quality control through the reduction of defects such as surface defects or dimensional defects, and through the reduction of consumable and resources being wasted for further processing of defective bars.

In **M24,** 4 NDIs were installed in-line, **in M34**, a new NDI was introduced in line (NDI#5 (laser line triangulation system for point cloud acquisition) (Figure 1). By **M40**, all NDIs were integrated with the platform, the digital twin featured updated models for the heating process together with overhauled visualizations of production and NDI data, all three quality assessment modules were available (DAT#0 for dimensional product predictions, DAT#1 for process parameters recommendation and DAT#2 for environmental impact calculation). Lastly, the DST was deployed, while the latest version of the openZDM platform and of the AAS Type 3 implementation are available.

| NDI#1 (laser line triangulation for straightness at the beginning of the heating process) | NDI#2 and #3 (thermal camera after the induction furnace | NDI#4 (laser line triangulation for straightness on high-temperature bars) | NDI#5 (3D vision. point cloud) | NDI#6 (vision-based system to detect visual defects) |
|---|---|---|---|---|

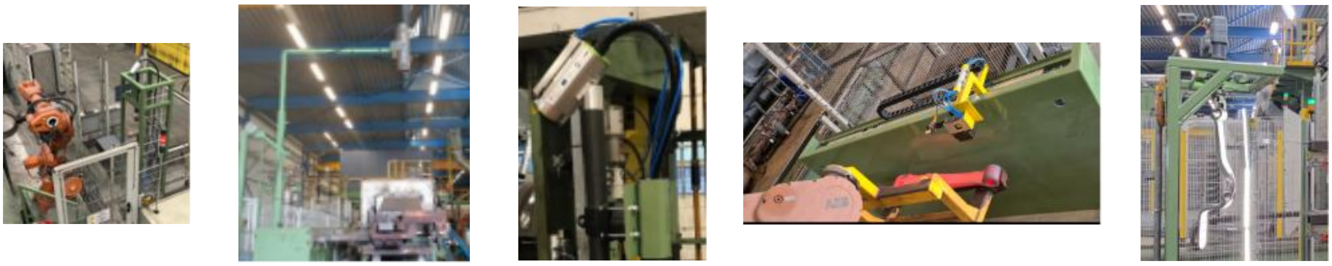

**Figure 1: Final NDIs operational in M42 in VDLWEW**

## 2.2 Components/ Key Assets

Below, minimum valuable products coming from WP3 and WP4 (such as equipment and software functionalities) have been customized and tested in WP5 in the VDLWEW line. The main assets used in the VDLWEW demonstration for M42 can be seen in Table 2.

**Table 2: Connections with other WPs in the VDLWEW use case**

| WP | Task name | Component name and description | Status in M24 | Status in M42 |
|---|---|---|---|---|
| 3 | Laser line triangulation instruments for geometry measurement (T3.2) | NDI#1: Laser line triangulation instrument for straightness measurements at low temperature | Prototype installed and ready for operation in-line. Network communication issues are under solution. Tuning of the measurement algorithms and optimization will follow. | NDI#1 in operation. After intensive use for 12 months, improvements in localization (to minimize light effect) were done. |
| | | NDI#4: Laser line triangulation instrument for straightness measurements at high temperature | Prototype installed and ready for operation in-line. Network communication issues are under solution. Problems of low Signal-to-Noise ratio encountered, due to bar radiation; they are being addressed by hw and sw improvements. Tuning of the measurement algorithms and optimization will follow. | NDI#4 in operation. After intensive use for 12 months, improvements in localization (to minimize high temperature effect) were done. |
| | | NDI#5: Laser line triangulation instrument for 3D dimension measurements of the product | Components ready for assembly. Final solution under development in laboratory. | NDI#5 in operation. |
| | Vision-based techniques (VIS and IR) for in-line defect | NDI#2: Vision based instrument for measuring the product's temperature profile after the induction furnace process | Final solution installed in-line and operational. Network connection issues encountered are under solution. | NDI#2 in operation. |

| WP | Task name | Component name and description | Status in M24 | Status in M42 |
|---|---|---|---|---|
| | detection (T3.3) | | Tuning of the measurement algorithms and optimization will follow. | |
| | | NDI#3: Vision based instrument for measuring the product's temperature profile after the descaling unit process | Final solution installed in-line and operational. Network connection issues encountered are under solution; this happened only after the installation of 3 other NDIs, thus demonstrating that the network bandwidth needs improvements. | NDI#3 in operation. |
| | | NDI#6: Vision based instrument for surface defects detection | The system available inline with real-time images being acquired | NDI#6 in operation. |
| | X-ray for residual stress (T3.4) | NDI#0&7: X-ray inspection technique for residual stress detection | Setup in laboratory and study of the correlation between residual stress and bending of bars ongoing | The results obtained are the outcome of an experiment conducted to determine whether there were differences in the measurement of residual stress between the two types of raw material supplied by the supplier. The result was derived from an overall analysis, not from measurements on each individual part, and no correlation was found between residual stress and bending of the bars. |
| 4 | AAS data models (T4.2) | Modelling of use case assets as AASs | NDI status messages under development. | Final AAS versions available with the Type 3 functionality operational |
| | Digital twin toolset implementation (T4.3) | DT responsible for conducting real-time simulations using real-time data from the VDLWEW processes and visualizes received process parameters' data | Updated visualization for the VDLWEW use case. Added point cloud data visualization, improved rendering, distance and area extraction tool added. Additional production parameters monitored. | Digital twin updated with an improved simulation model of the heating process and revamped visualization dashboards for improved ease of use. |
| | Data-driven quality assessment modules (T4.4) | Data-driven quality assessment modules capable of conducting predictions of dimensional characteristics and identified possible oxide position on the bar using NDI#3 data | Additional machine-learning predictive models have been created from newly collected historical data. These enable the predictions of dimensional characteristics as well as the forecast of their maximum deviation for future products. | DAT#0 has been retrained for multi-target dimensional properties prediction. XAI-based layer on top of DAT#0 for root-cause provision. DAT#1 provides recommendations for the rolling mill temperature correction parameter, |

| WP | Task name | Component name and description | Status in M24 | Status in M42 |
|---|---|---|---|---|
| | | | | and DAT#2 performs LCA through the platform deployed on the line. |
| | Decision support tool for alternative process configurations (T4.5) | DST responsible for conducting alternative what-if as inputs and the dimensional defects disclosed in deliverable 2.1 as cost/benefit indicators | The optimization component of the decision support tool has been improved with the inclusion of minimization and differential evolution algorithms that have been tested in the pilot. | Fully implemented on the line, providing recommendations to reduce defects, surface oxide percentage, and global warming potential. |
| | openZDM platform business layer and integration of enabling solutions (T4.6) | openZDM platform responsible for providing access to the WP4 components to the user through a web-based application | In VDL Weweler, the latest version of the existing components has been deployed including, the user interface frontend & backend application, and the AAS middleware that holds the AAS models and their data. The updates include new look and feel in the UI, support of new features such as the new administrator functionality for viewing AAS information and performance updates. | Final version of the platform deployed in VDLWEW (multilanguage support for improved ease of use). The AAS Type 3 for per-product AAS creation is available. Updated administrator view with improved performance and data download. E-mail, SMS, and UI notifications. IDS implementation for induction furnace data communication (temperature distribution, furnace parameters) to INDUCTION, facilitating knowledge extraction on the performance of the furnace for INDUCTION. |

## 2.3 Demonstrator

The digital twin visualization supports 3D, 2D and point cloud visualization of the line (Figure 2). All NDI views (laser line triangulation, thermal cameras, NDI#5 and NDI#6) include CSV data download and visualisation of captured raw and extracted measurements.

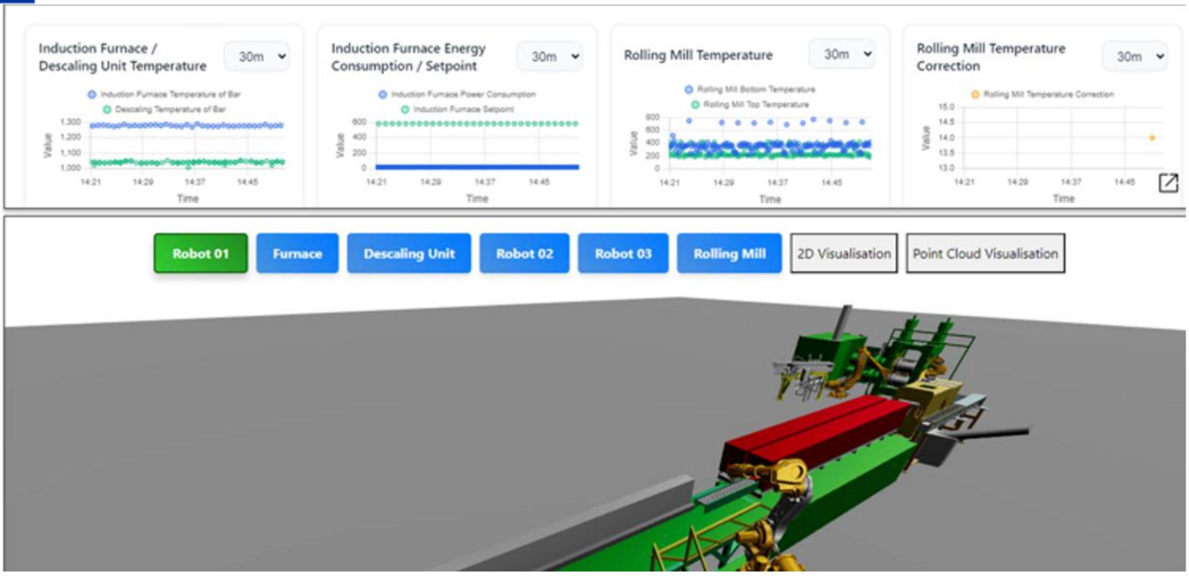


**Figure 2: The final digital twin dashboard of the VDLWEW.**

All DATs of VDLWEW operate in real-time with data from both the production processes and NDIs. The exception is DAT#2, which performs LCA calculations based on available LCI data that can be manually updated. In addition, the DST is also deployed in the pilot supporting alternative scenario analysis and evaluation to minimise the number of defects, the environmental impact and the percentage of oxides in the heated product. Its landing page is seen in Figure 3.

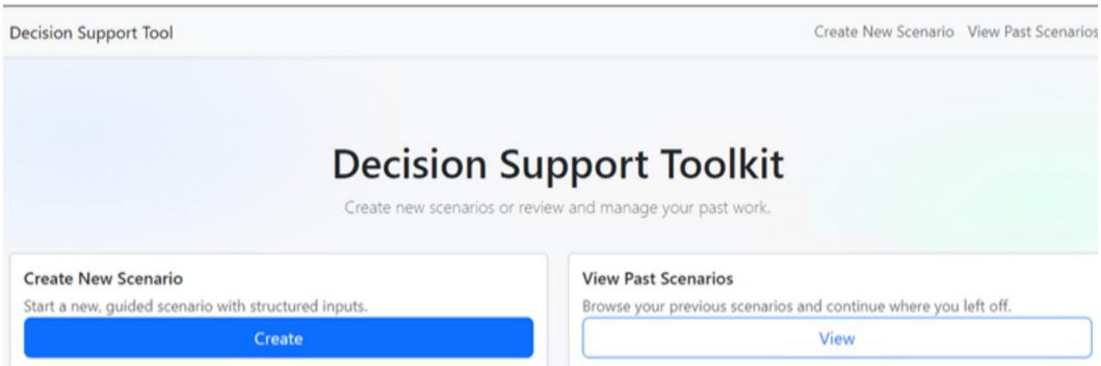


**Figure 3: The landing page of the DST view of the VDLWEW pilot.**

# 3 Vehicle body Shop and final assembly demonstrator (VWAE)

## 3.1 Overview

Volkswagen Autoeuropa (VWAE) is an automotive industry located in Portugal (Palmela) and a production plant of Volkswagen Group. It manufactures T-ROC models for VW. VWAE use case focuses on the quality control of the flush and gap in T-ROC models, that are mainly checked in two different areas of the factory: i) the Body Shop where the car is not painted, and the measurements are performed on the chassis of the car; and ii) the Final Assembly where the car is in its final shape, painted and with all the different components assembled (Example: doors, lights, rear glass…).

Moreover, in the Body Shop gap and flush measurements are performed automatically in different stations using already installed commercial laser profilometers, and data are saved on the VWAE internal database, named FIS. The commercial laser profilometers and the FIS are legacy systems of the VWAE use case. While in the Final Assembly, the checks are performed by operators, using mechanical gauges and no data are available. In the Body Shop gap (related to the distance between the parts) and flush (related to the height difference between the two parts) measurements are performed automatically in different stations using already installed commercial laser profilometers and data are saved on the VWAE internal database, named FIS. The commercial laser profilometers and the FIS are legacy systems of the VWAE use case. While in the Final Assembly, the checks are performed by operators, using mechanical gauges and no data are available. One of the outcomes of the openZDM project involves the development of NDIs, and more specifically, for this use case the NDI#8 named G3F, consisting of a portable laser line triangulation sensor that will be used in the final assembly line to replace the mechanical measuring instruments and enable the collection of alignment data in this area. Figure 4 illustrates the inspection stations located in the Body Shop and the Final Assembly areas, providing a clearer description of the assembly line.

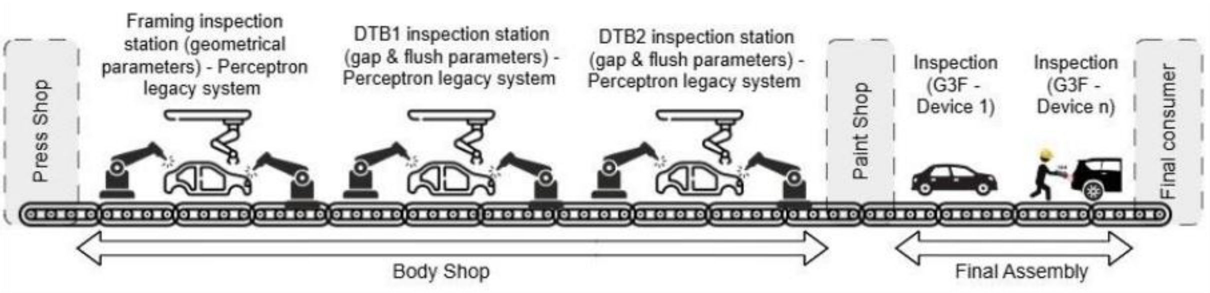


**Figure 4: Layout of the sequence of the inspection stations in the Body Shop and Final Assembly areas**

## 3.2 Components/ Key Assets

From developments in WP3 and WP4, Minimum viable products like equipment and software functionalities have been customized and tested in WP5 in the story of the improvement for VWAE assembly line. The main assets used in the VWAE demonstration for M24 include the following integrated and non-integrated components developed in WP3 and WP4 as they can be seen in Table 3.

**Table 3: Connections with other WPs in the VWAE use case.**

| WP | Task name | Component name and description | Status up to M24 | Status in M42 |
|---|---|---|---|---|
| 3 | Laser line triangulation instruments for geometry measurement (T3.2) | NDI#8: portable laser line triangulation for gap and flush measurements | 20 NDI#8 Prototypes have been assembled and 3 of them are fully integrated in the Body Shop and Final Assembly. Data acquisition and data storing in the openZDM platform are working in real production conditions. | The 20 NDI#8 have been updated and ready for the integration in the production line. A number is already in use both in the Body Shop and in the Final Assembly and one has been integrated on a robotic arm. |
| 4 | AAS data models (T4.2) | Modelling of use case assets as AASs | Type 2 AAS for framing, DTB1 and DTB2, have been fully developed and deployed in the VWAE infrastructure. Type 1 AAS for NDI#8 and the product has been fully developed, and the type 2 and 3 versions for these models are ongoing. | Type 2 AAS for NDI#8 and the product have been fully developed and deployed in the VWAE infrastructure. Type 3 AAS has been fully developed. |
| | Digital twin toolset implementation (T4.3) | DT responsible for conducting real-time data monitoring using real-time data from the VWAE processes and visualizes | Specification of a DT architecture following the ISO 23247 standard. The data collection and analysis module was extended to cover also the Final assembly area (data from G3Fs devices), providing also analytic tools for diagnosis in addition to the predictive and monitoring analytics. A first | DT is fully implemented and accessible to the openZDM platform through the VWAE server. The modules of data collection, data analysis and simulation, and visualization was completely integrated |

| WP | Task name | Component name and description | Status up to M24 | Status in M42 |
|---|---|---|---|---|
| | | received process parameters' data | version of the what-if simulation service was integrated, and the visualization module was deployed through 2D interfaces. The DT was deployed and made accessible to the platform through the VWAE server. | covering the entire assembly process. |
| | Data-driven quality assessment modules (T4.4) | Data-driven quality assessment modules capable of conducting predictions of gap and flush data | New Data-driven quality assessment modules were created: The first one, using Machine Learning models, has the goal to use historical data from the present station to predict the values (critical points/measures) of the following one. The second is to analyse the data acquired in different measuring equipments (Perceptron and Quirl) and notify VWAE when measurements are not similar, and therefore, need to be adjusted by VWAE. The third enable the diagnosis of the anomalies found, providing explanation about possible causes. | Body (Perceptron) models were refined, and intermediate models between Body and Assembly (G3F) were developed. Some approaches were reused, while additional ones were explored to address various challenges and to drive continuous improvement. |
| | Decision support tool for alternative process configurations (T4.5) | What-if simulation tool for analysing impacts on quality limits at measurement points based on hypothetical measurement values. | Two what-if simulation tools were implemented for the VWAE case study. The first tool focuses on exploring correlations among measurement points to generate predictive models, leveraging explainable AI strategies to improve models' accuracy. The second tool assesses the impact on critical measurement points resulting from hypothetical variation in correlated measurements. | Improvements were made to simulation tools to enhance their predictive capabilities. The tools have been successfully integrated into the openZDM platform hosted on the VWAE server. The user interface was also improved, aiming to enable a better exploration of the developed tool. |
| | openZDM platform business layer and integration of enabling solutions (T4.6) | openZDM platform responsible for providing to the user through a web-based application. | The latest version of all the platform components has been deployed locally in VWAE server. This includes the user interface frontend and backend components, the Identity server, service discovery, and the accompanying databases. | All components have been updated to the latest versions. Experiments have been carried out to verify all platform components against the pilot requirements. |

## 3.3 Demonstrator

**Laser line triangulation instruments for geometry measurement NDI#8.**

At M42, the 20 sensors have been updated with the latest SW to implement all the improvements developed and tested during the last period.  The results obtained are encouraging and the distributions of some points measured in the last period have been reported. 10 points are usually measured in each car, and for each point both Gap and Flush are calculated. Then through Wi-Fi, the acquired data are sent to the VWAE server.

Moreover, one G3F has been mounted on a collaborative robotic arm available on the VWAE premises. The installation has been done outside the Body shop line. The G3F has been modified both at hardware and software level, to be integrated and controlled by the robot. In Figure 13 the G3F integrated in the collaborative robotic arm is represented.

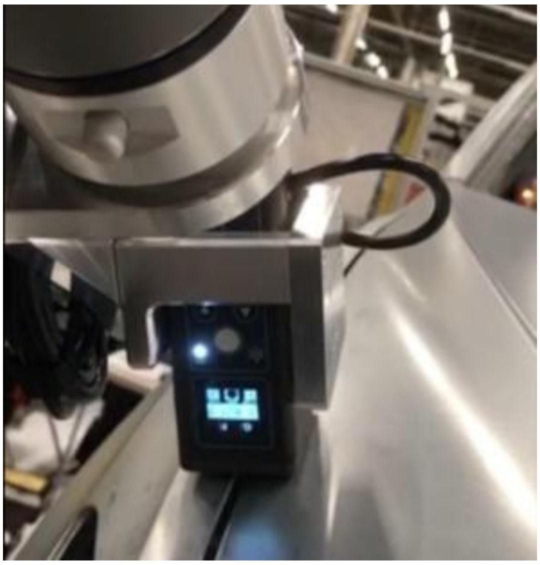

**Figure 5: NDI#8 integrated in the collaborative robotic arm**

**Digital twin toolset implementation**

By the end of the project (month 42), the DT has been fully implemented, with all modules integrated and accessible via the VWAE server within the openZDM platform. Figure 7 depicts the proposed architecture used for the implementation of the DT in this use case, which is based on the ISO 23247 standard. It integrates the data collected (via AAS) from the inspection stations to feed the digital model representing the assembly process and to encapsulate a set of functionalities that contribute to improving assembly process efficiency and product quality.

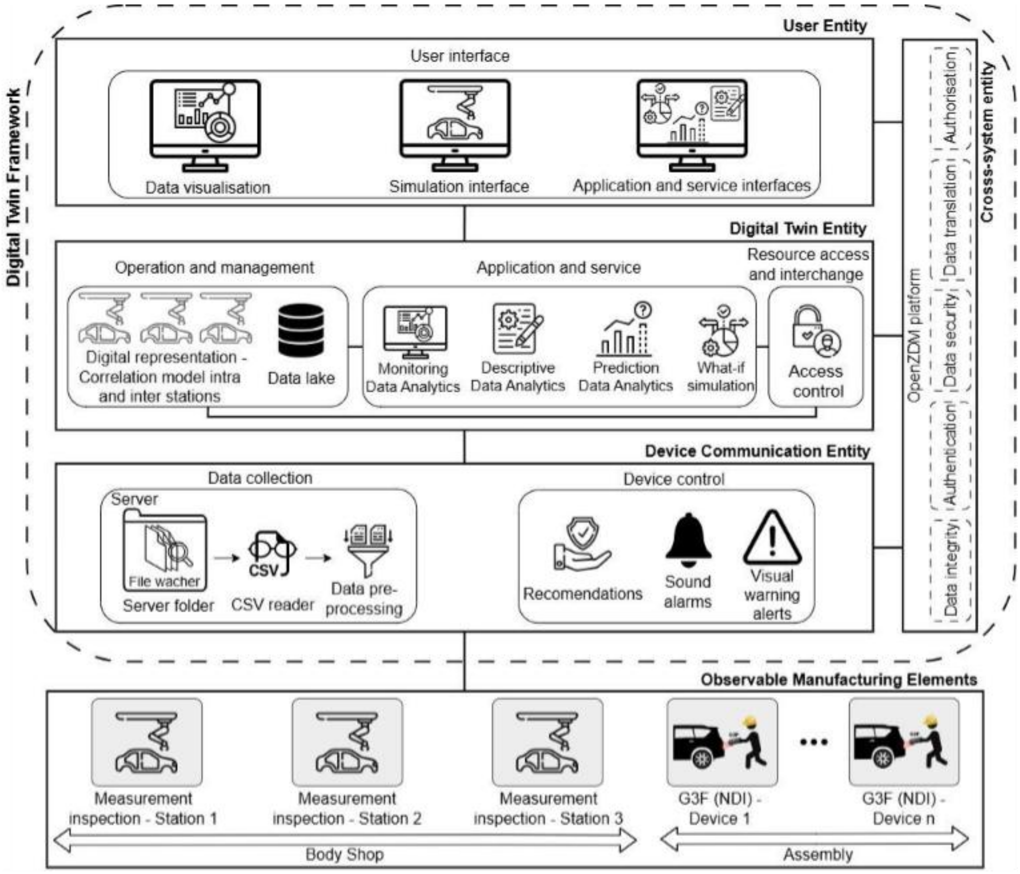


**Figure 6: DT architecture for the measurement process in the body shop and final assembly of the VWAE assembly line [5].**

The results obtained demonstrate that the implemented DT effectively enabled the management and analysis of the available data from the assembly process by integrating the different functionalities of real-time monitoring, prediction, and different scenario analysis of fitting limits. By providing a dynamic digital representation of the assembly process synchronized with live data streams, the DT supported proactive process optimization and improved production outcomes. The proposed implementation validates its applicability in real industrial environment, highlighting the improvements that this type of technology can provide when applied in a manufacturing context. For instance, Figure 7 illustrates one of the implemented DT functionalities, namely the user interface created to present a graphical 3D simulation aiming to help in the identification of the critical points that are being measured.

Figure 8 illustrates the workflow adopted for model training and validation. To ensure that the most accurate models were selected and that they generalized well. Models were evaluated over different time windows and trained both on the period with the largest sample size and on the full dataset.

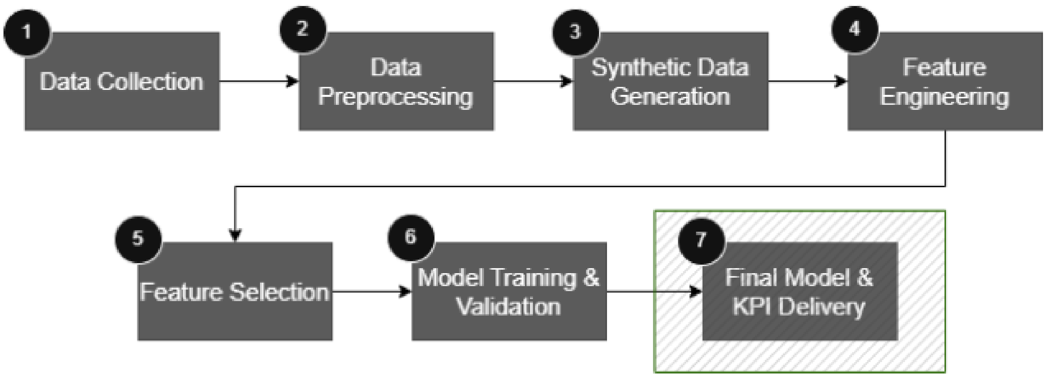


**Figure 7: Data Processing and Model Training Workflow**

# 4 Wood board manufacturing demonstrator (SONAE)

## 4.1 Overview

SONAE ARAUCO manufactures wood-based panels, being one of the main worldwide players in this industry. Production of wood boards production is made through a continuous process involving the feeding of raw materials (wood and resins from external suppliers), their processing (through heat and pressure) and finishing of the panels (sanding and cutting) and/or further processing (such as surfacing with decorative paper) (Figure 9). The use case is focused on the production of decorative wood boards.

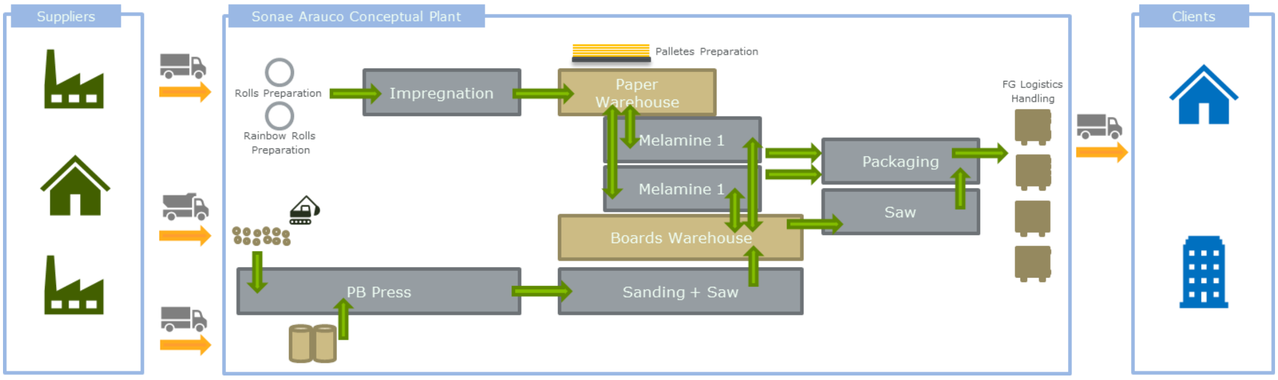


**Figure 8: Sonae Arauco pilot description.**

Decorative wood boards are produced by coating raw boards with impregnated papers, which are prepared in impregnation lines and then pressed onto the boards using specific temperature and pressure settings. After pressing, each panel undergoes manual visual inspection, a repetitive and demanding task that identifies defects only after production, leading to downgraded products and financial loss.

The pilot aims to detect defects before they occur using a data-driven, preventive approach, improving sustainability and reducing waste. Additionally, insights from defect detection will support product development by helping define optimal parameters for new products.

## 4.2 Components/ Key Assets

The connections with the developments performed in other WPs until the end of the project (M42) are presented in Table 4.

**Table 4: Connections with other WPs in the SONAE ARAUCO use case**

| WP | Task name | Component name and description | Status M24 | Status in M42 |
|---|---|---|---|---|
| 4 | AAS data models (T4.2) | Type 2 for 2 components (infeed station and short cycle press) have been successfully completed. | AAS are now used as a data format to communicate between the components (DATs). | AAS are now used as a data format to communicate between the components. |
| | Digital twin toolset implementation (T4.3) | It will be implemented a Grafana visualization through an instantiation developed in the scope of the Digital Twin Toolset. | The 2D visualisation of the SONAE pilot will be created, with real-time data visualisation on top of it. | Update of dashboards for DATs results visualization, including the addition of the dashboard for DAT#4. |
| | Data-driven quality assessment modules (T4.4) | Data analytics is ongoing in data prediction for DAT#3, which predict if a produced product will have a defect. After predicting a defect, the algorithm explains the reason, providing the parameters with higher impact, and recommends | Improved DAT#3 with a new architecture based on LSTM, and a larger number of defects is considered. It has an accuracy of 80%, and it is only dependent on the latest sample, which allows a granularity of defect prediction by board. A new development was also | Improvement of DAT#3 defect prediction results by including environmental data (temperature, humidity), shift information and boundaries analysis. Fix of minor |

| WP | Task name | Component name and description | Status M24 | Status in M42 |
|---|---|---|---|---|
| | | changes in them to avoid the defect. DAT#5 is a data model that analyses the accuracy of models, for DAT maintenance in accordance with their expected quality. | made regarding DAT#5, a model that analyses the accuracy of the other DATs, mainly DAT#3. Both DAT#3 and DAT#5 are now in in a container communicating as an HTTP service. | issues with DAT#5 execution. |
| | Decision support tool for alternative process configurations (T4.5) | It will be implemented real time data collection with partial descriptive and predictive analytics. | - | Implementation and deployment of DAT#4, for simulating the new products. |

## 4.3 Demonstrator

The openZDM dashboards for this use case consist of four interface modules tailored to different roles. Operators use the Real-Time Defect Prediction module to monitor defect probabilities and trends, while Supervisors rely on the Parameter Recommendation view to review and approve optimized machine settings. Product engineers use the New Product Simulation Module to input panel characteristics, simulate production scenarios, and obtain optimal parameters and predicted quality yields for new product development. Planners use the Production Plan Simulation tool to evaluate full production schedules via CSV upload, identify high-risk orders, and adjust parameters or reschedule before production, with options to download or archive results.

For product development, the New Product Simulation Module enables engineers to input panel characteristics and simulate production scenarios (Figure 9).

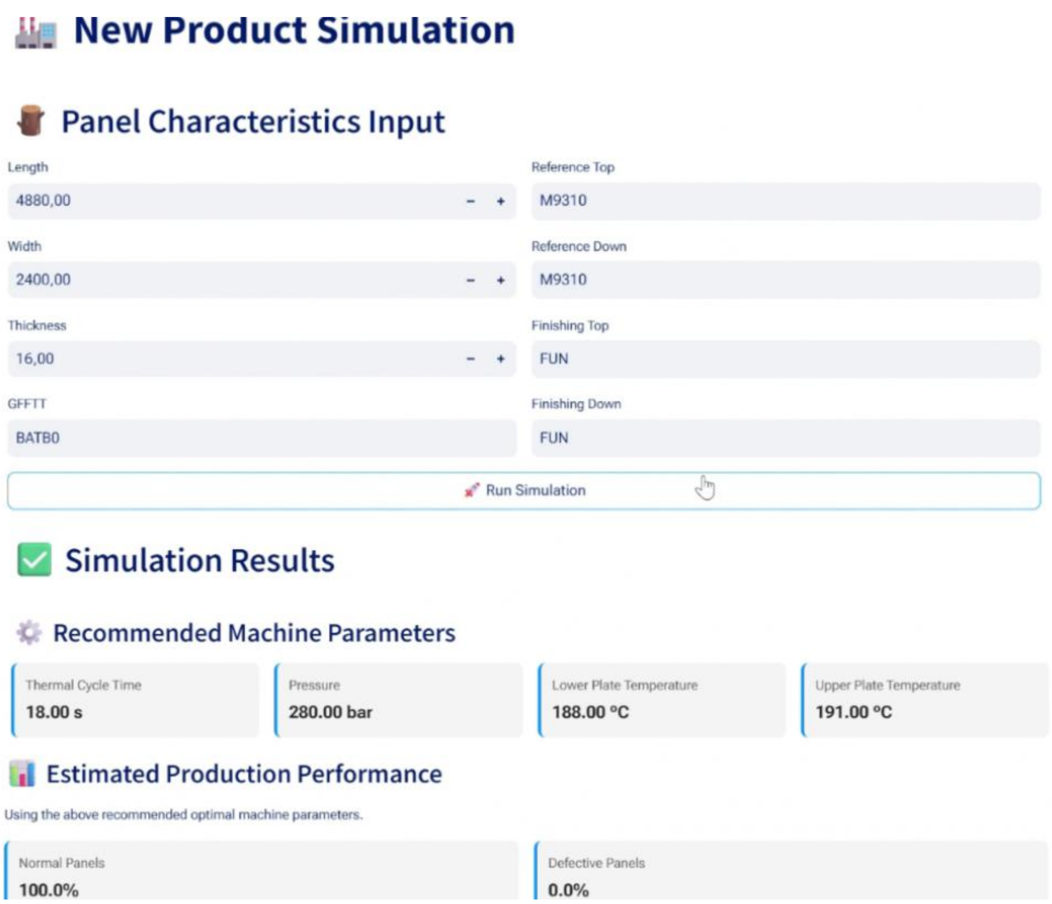


**Figure 9: OpenZDM's Sonae Arauco New simulation module.**

Finally, the Model Performance & Validation Monitor facilitates post-production auditing. By filtering data by Production Order Code, this dashboard compares the AI's predicted defect counts against the actual defects reported by operators, providing a direct metric for validating and maintaining model accuracy.

The AAS, present in the platform, is being used as the main data structure input for the data models and to store data in real time. A comparison has also been made between the current SONAE ARAUCO solution and the openZDM platform regarding the AAS creation.

# 5 Bottle manufacturing demonstrator (VIDRALA)

## 5.1 Overview

VIDRALA use case manufacture glass through the forming method, employing both blowing-blowing and blowing-pressing techniques. (https://www.youtube.com/watch?v=B-h65k7k-e8&t=185s ). There are 19 furnaces among these 8 plants worldwide located, with more than 70 production lines. In the forming stage (part of the hot-end) this stage bottles had a temperature of 700 degrees Celsius and two images are taken from each bottle using thermal cameras. In the project these images and other hot-end data are being used to predict wall thickness issues, that can be measured only later in the production line at the quality control station, where the bottles cool to room temperature.

The openZDM project demonstrator focuses on the quality prediction of the bottles at the forming stage, long before inspection is don (45 to 90 minutes).

Additionally, other important parameters that influence the quality – thickness of the bottle, such us: the cavity of the forming machine and the glass gob, are being considered. All the available data is being analysed to achieve the optimization of the hot-end area parameters to reduce the risk of having wall thickness issues during the manufacturing process.

## 5.2 Components / Key Assets

Table 5 summarized the minimum valuable products (MVP) coming from WP3 and WP4 (like equipment and software functionalities) that have been customized and tested in WP5. The evolution of the implementation is summarized in the table, containing the final results of openZDM.

**Table 5: Connections with other WPs in the VIDRALA use case**

| WP | Task name | Component name and description | Status up to M24 | Final status in M42 |
|---|---|---|---|---|
| 3 | Vision-based techniques (Thermal images) for bottle thickness estimation | NDI#9a: Expert system for bottle thickness. First model generated and dockerized. | Better predictions have been achieved for NDI9a after revision of initial hypothesis and new experiments. | Three quality points estimations:<br>TOP R2= 0.85.<br>MEDIUM R2= 0.84.<br>BOTTOM R2= 0.93.<br><br>However, it is not representative for all cavities. |
| 4 | AAS data models (T4.2) | Type 2 AAS for Expert System NDI#9a. | New AAS for VIDRALA product based on bottle batches of 5 minutes. | NDI9a and NDI9b operative with real time data from ELTON's plant. |
| | Digital twin toolset implementation (T4.3) | DT responsible for conducting real-time simulations using real-time data from the VIDRALA processes and visualizes received process parameters' data. | Visualization integrated in openZDM platform.<br><br>Syntethic data generation in process time.<br><br>Front-end/back end **composer.**<br>Dashboard in graphana | Digital twing visualization in openZDM platform.<br><br>Real time data from ELTON's plant.<br>Front-end/back end composer operative.<br>Dashboard with alarms implemented. |

| | | | | |
|---|---|---|---|---|
| | | Dashboard interaction in time process | | |
| | Data-driven quality assessment modules (T4.4) | Data-driven quality assessment modules capable of conducting predictions of bottle quality by using hot-end data. | First results from NDI9a data correlation have been obtained:<br>Selecting a 5 minutes window as base time to obtain valuable data.<br>Revealed a problem in the thickness analysis. | DAT#6 and DAT#7 with the bottle segmentation and the recommendations for the optimal gob shape are operative. |
| | The openZDM platform implemented in-cloud | | Tested in MSI architecture, combined with VIDRALA's DT In the cloud. | openZDM platform operative and pilot implementation has been standardized. |

## 5.3 Demonstrator

**NDI#9b:** Related with the analysis of the gob, NDI#9b was defined in a similar way than NDI#9a. After extensive analysis of the line process data and gob features, it was limited the achievements regarding the importance of the gob in the final quality of the bottle, for further information check the publication by [7]. However, part of the conclusions can be reused as the calculation of the optimal values in each of the gob features that produce quality bottles. Those values according with the bottle model are included in Vidrala's digital win and will be integrated in the dashboard according with the model to be manufactured.

**Data Analytics tool:** Pipeline for data processing. DAT #5 and DAT#6. VIDRALA's pilot is looking to obtain an estimation for bottle thickness and a recommendation of process parameters for fitting regarding the gob. DAT#5 is a generalization of bottle thickness estimator. DAT#5 is a public result by TEC, and it is offering the capabilities of the bottle segmentation, expanding the possibilities of NDI#9a use.

Regarding DAT#6, all data analysis was carried out within WP4, and part of this work was presented at ETFA 2025. The analysis identified the optimal length and tilt values based on data from the Elton EL14 dataset for model 5114/037. By monitoring the GobScan variables, it is now possible to define alarms and access optimal process parameters. Nevertheless, the comprehensive analysis of datasets has enabled the identification of optimal gob feature ranges for each analyzed model. This information has been integrated into the DT line and will be used for real-time comparison, alongside other bottle design parameters, to inform operators of any gob deviations.

**Product AAS:** It was created and presented in [3]. It was explored the use of AAS in processes where the unique identification of each part manufactured in the line is not available or feasible and proposes the batch of parts as feasible solution. **Digital twin in openZDM platform**: it was early implemented in M24 with offline data, now it is fully online, and it was enriched with an historic of relevant events and alarms:

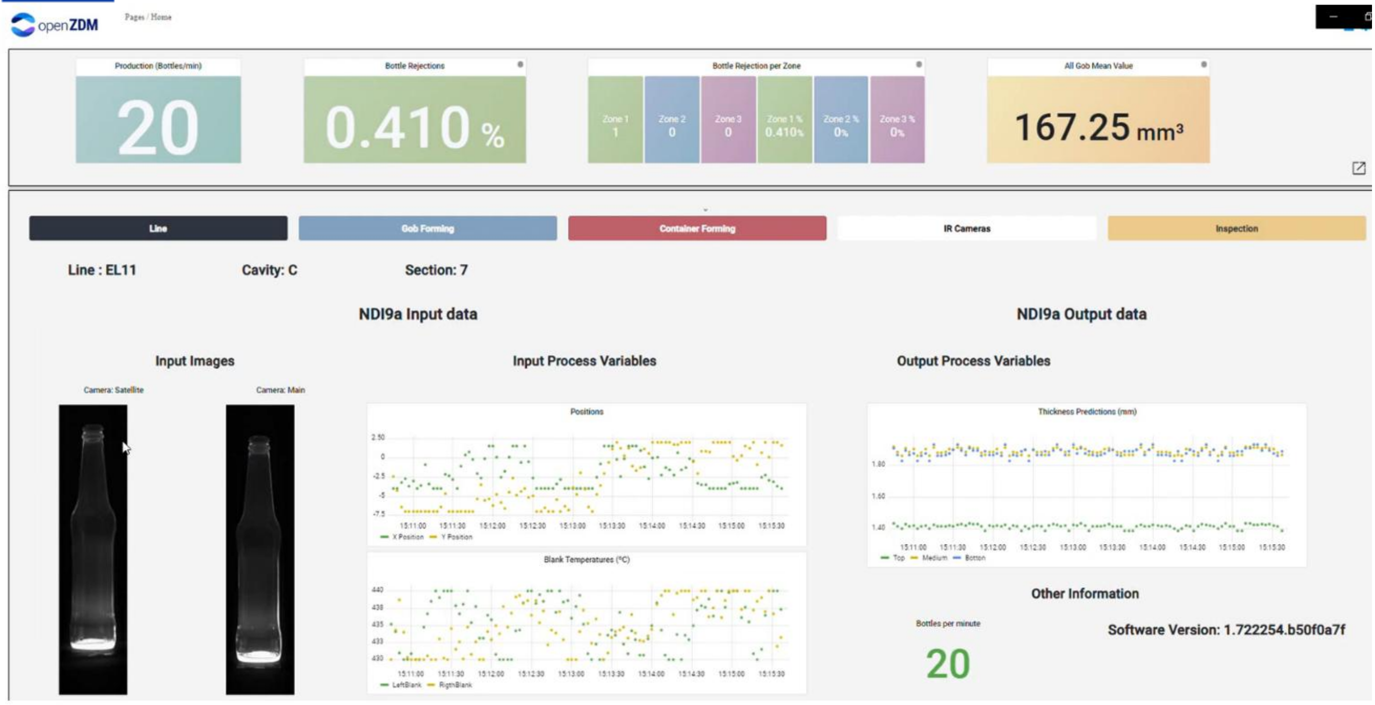


Figure 10: VIDRALA's NDI data visualization in openZDM platform.

The composer has been fully tested within VIDRALA's components and openZDM services, with the plant dashboard (Figure 11).

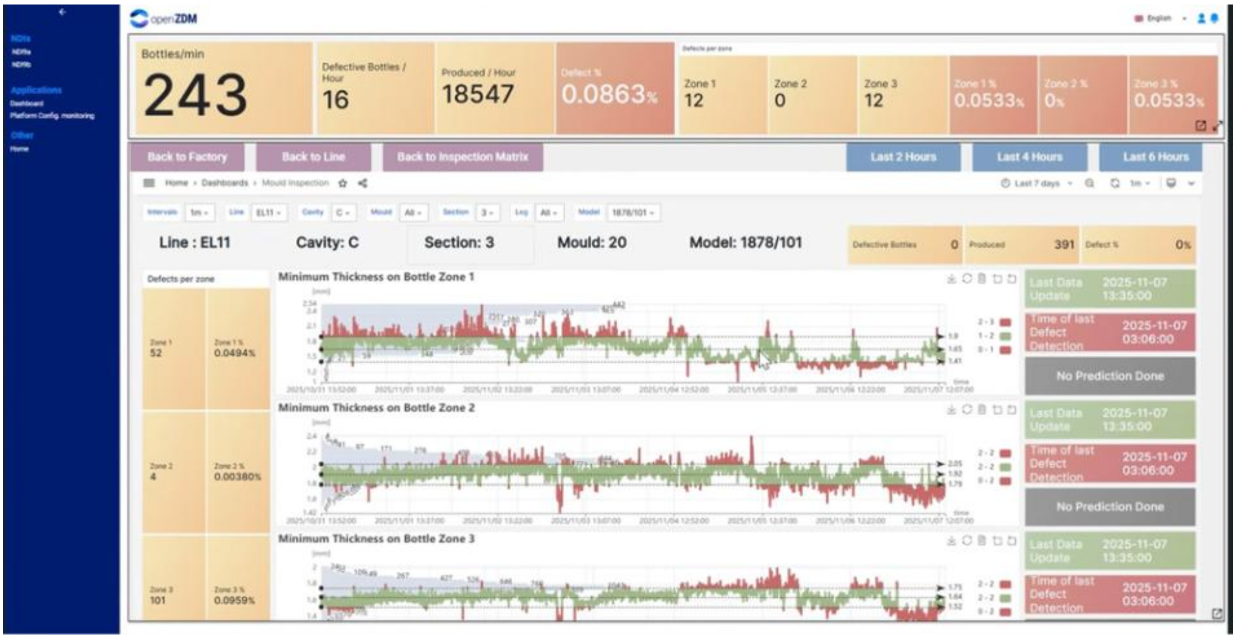


Figure 11: OpenZDM Dashboard.

Regarding LCA calculations, with calculations based on 2-week production (43 Tn/day), 50 minutes lehr time on average and 185 WT defect events registered. The percentage of reject due to WT is around a 2%:

- 0,874 Tn/day → 95K€ per year.
- With a 50% reduction on WT defects, the savings will be 47K€ per line & year and ~50 Tn $CO_2$ reduction per line & year.

# 6 EV battery production use case (APTIV)

## 6.1 Overview

APTIV is a manufacturer of battery trays for electric vehicles. APTIV produces 2 types of battery trays which either include 3 cells welded on each side of the tray or 4 cells welded on each side. APTIV is in Turin, Italy. The use case is focused on the processing of battery cells and welding the processed battery cells into battery trays for electric vehicles. The main objective in the use case is to provide a set of tools to achieve process monitoring and proactive quality control via the reduction of the defects identified after the welding process and after the manual handling.

NDI#10 and NDI#11 (Figure 12) are installed in the APTIV line and are communicating data to the local MQTT broker enabling their integration with the openZDM platform and its components. NDI triggering has been adjusted to improve the time of acquisition. Similarly, illuminators of NDI#11 have been adjusted to avoid potential black images and spots. Additionally, the NDI#11 defect detection algorithm has been updated, supporting not only missing welds but also aesthetical defects on the welds. This functionality is available through the APTIV digital twin. Both quality assessment modules for process monitoring and optimization are available, with the first (DAT#12) being displayed through the digital twin and the second (DAT#13) being incorporated within the DST.


**Figure 12: NDI#10 and #11 installed in-line in APTIV (M42).**

## 6.2 Components/ Key Assets

From developments in WP3 and WP4, Minimum valuable products like equipment and software functionalities have been customized and tested in WP5 in the story of the improvement for the APTIV manufacturing line.

The main assets used in APTIV demonstration for M24 include the following components, as they can be seen in Table 6.

**Table 6: Connections with other WPs in the APTIV use case**

| WP | Task name | Component name and description | Status up to M24 | Final status in M42 |
|---|---|---|---|---|
| 3 | Vision-based techniques (VIS and IR) for in-line defect detection (T3.3) | Vision based instrument for detection of welding process defects (NDI#10 – Cassandra System) | NDI#10 is being used in the APTIV line since M12, and necessary improvements in M20 have been detected. The data collected has been used for 10 months | The software of NDI#10 has been improved to better manage edge cases. NDI#10 is integrated with the platform for real-time data communication. |
| | | Vision based instrument for welding process monitoring and aesthetical defects detection (NDI#11) | The preliminary correlation of data between NDI#10 and NDI#11 has been initiated. Images are being collected and manually classified to define defect identification. | The NDI#11 software is deployed in APTIV identifying both missing welds and spots on the weld with a combined CNN and YOLO algorithm. NDI#11 data arrive to the platform. |
| 4 | AAS data models (T4.2) | Modelling of use case assets as AASs | The inclusion of NDI status messages in the AAS of NDIs is currently under development. | Latest versions of process, product and NDI AASs are available in the platform and populated with real-time data. |

| WP | Task name | Component name and description | Status up to M24 | Final status in M42 |
|---|---|---|---|---|
| | Digital twin toolset implementation (T4.3) | DT responsible for conducting real-time monitoring of the APTIV process and visualizes received process parameters' data | The extraction of features from NDI data with the digital twin is in progress, while a feedback collection pipeline is under development. This targets the improvement of the NDI#11 algorithm based on operator feedback. | Updated process visualizations available with new NDI dashboards. Integrated with DAT#12 for process KPI monitoring. Integrated with process and NDI data via the platform MQTT. |
| | Data-driven quality assessment modules (T4.4) | Data-driven quality assessment modules capable of monitoring and visualizing the real-time production data and conducting descriptive data analysis using real-time data | The first models trained with real data provided by NDI#10 have been achieved. The initial model for NDI#11, with real pictures provided by NDI#11, has been trained. | DAT#12 visualizes real-time KPIs such as mean time between defect. DAT#13 capable of parameter recommendation of the welding process integrated with a simplified version of the DST. On top of DAT#13, an XAI layer provides the root-cause analysis for the recommended parameter. |
| | openZDM platform business layer and integration of enabling solutions (T4.6) | OpenZDM platform responsible for providing access to the WP4 components to the user through a web-based application | Some components of the Platform have been moved from the existing local server to the Linux server in the production line in order to make data exchange more effective and real-time. | Latest version of the platform deployed with multilanguage support, UI notifications and the final version of the Type 2 AAS interface. |

## 6.3 Demonstrator

In the local platform of APTIV, the updated models for NDI#11 are now available. The outputs of the models are exposed to the digital twin of the use case, where they are visualized. Based on APTIV requirements for simplicity and ease of use, the outputs of NDI#10 are visualized through a table-based interface where OK/NOK detections are shown for each NDI#10 camera together with the modules' unique identifier. For NDI#11 (Figure 13), and to facilitate the work of quality managers within the pilot, defect identifications are shown together with respective 2D images in separate views, one for missing weld defects and one for aesthetical defects (spots) on the weld.

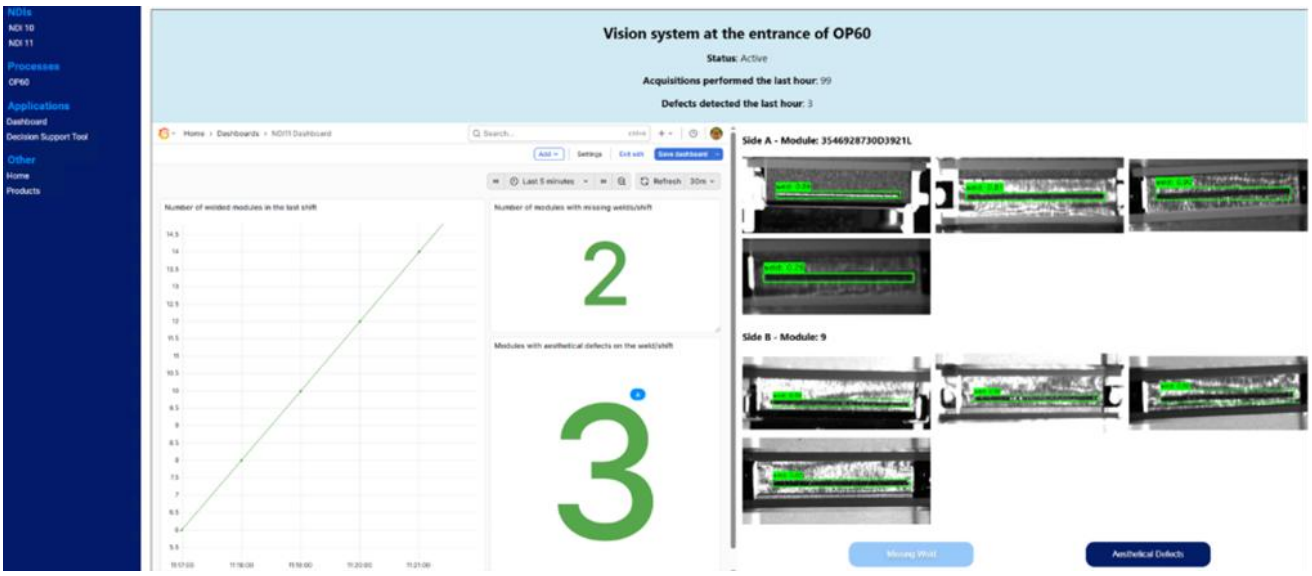


**Figure 13: Visualization of the NDI#11 algorithm's outputs.**

The next result of the APTIV pilot is its digital twin. The digital twin has been updated to feature a new 2D visualization of the robotic arm performing the welding, as well as with a new point cloud visualization of the station with advanced measuring capabilities. Such functionality was critical for maintenance personnel in cases where they needed to extract specific distances of components of the process while it was still in operation to avoid slowing down production. This result is illustrated in Figure 14, the dashboard of DAT#12 is visible that computes core quality KPIs such as the mean time between defects and the cycle time of the monitored process.

The last result from the APTIV pilot is the DAT#13 and DST. The DAT#13 core model has been incorporated into the DST of APTIV. The DST exposes a more simplified user interface than the one in the VDLWEW pilot given the reduced needs for parameter optimization in the specific pilot.

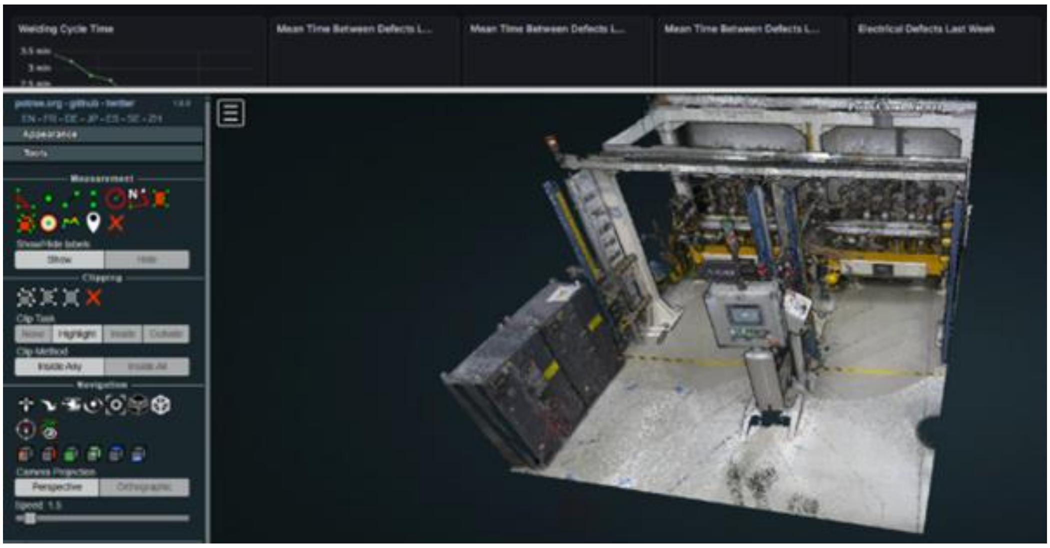


**Figure 14: The point cloud of the process presented via the APTIV digital twin.**

# 7 Lessons learned

The overall impression of the work done in openZDM is positive, allowing the pilot leaders to follow the scientific development of the AI training models and the openZDM platform, with all the standardisation, legacy systems and customisation required. From the companies, the level of development is still far from implementation, but they recognise the potential of the results.

Within openZDM, the highest-rated aspects were the collaboration between partners and technical teams, the efficiency of project management, and the willingness of companies to continue collaborating in future opportunities. However, the perception of the final TRL of some results and how those are not production-ready solutions affected the overall score, but provides valuable feedback for the interested partners' next steps.

# 8 Impact on openZDM concept and AI recommendations in Manufacturing

While artificial intelligence (AI) is widely celebrated for its transformative potential in manufacturing, its practical application faces significant challenges, while more and more applications are found along the production lines. For a comprehensive overview of AI in manufacturing, including SoA perspectives and future directions, refer to [2]. A critical barrier lies in the integration of hardware elements, including data extracted from manufacturing processes and newly installed non-destructive inspection (NDI) systems, which complicate AI deployment and the pursuit of zero-defect manufacturing. These challenges are compounded by the need to ensure the reliability of AI models. Despite these hurdles, the economic potential of AI in manufacturing remains substantial: PwC estimates that AI could contribute up to $15.7 trillion to the global economy by 2030, with manufacturing as a key beneficiary [6], [1]. Even as debates about a bubble and AI's profitability persist [8], tangible progress in AI-driven manufacturing is already evident, particularly in quality control and predictive maintenance.

The openZDM project addressed AI and zero defects manufacturing by pioneering the integration of real-time process data into state-of-the-art (SoA) data models, enabling quality recommendations to prevent defective parts at the production line's end. Through five pilot cases, the project tackled diverse challenges, from developing innovative NDI methods to testing the openZDM platform in five industrial scenarios. Key outcomes included 23 peer-reviewed journal publications [4], the deployment of a novel market-ready device (G3F), the creation of one patent, and the application of 12 data models in production lines.

The project demonstrated the feasibility of AI-driven quality improvements. Automated inspection and defect detection, particularly via computer vision, were implemented in all the pilots. These efforts align with Gartner's prediction that 50% of manufacturers will adopt AI in quality control by 2025, achieving a 30% improvement in defect detection [6]. Similarly, AI-powered predictive maintenance, as highlighted by McKinsey & Company, can reduce maintenance costs by 10–15% and downtime by up to 50% [8].

Data-driven decision-making was central to the project, with pilots demonstrating varying success levels:

- **High accuracy**: Models achieved near-perfect alignment with actual values (e.g., measuring gaps between car parts, detecting battery defects).
- **Conditional accuracy**: Models provided useful estimates but required additional validation to avoid false positives (e.g., correlations in paper and glass manufacturing).
- **Statistical insights**: Even when direct correlations were unattainable, expanded data access enabled statistical rate detection (e.g., car assembly, bottle production).

Other important conclusion was the on-premises deployment of solutions, even if cloud-based testing was considered as core at the project beginning, on-premises was prioritized to address cybersecurity concerns and facilitate IT collaboration, ensuring seamless integration into daily operations. It was, finally, the preferred openZDM platform installation.

With the openZDM project, we have discovered that we underscored the importance of involving operators in AI model implementation, bridging the gap between technological innovation and practical adoption. While challenges persist, the project's partners—VDLWEW, SONAE, VIDRALA, APTIV, and VWAE—are already advancing these solutions. By addressing technical, operational, and trust-related barriers, openZDM has laid a foundation for scalable AI integration in manufacturing, paving the way for the industry's evolution toward zero-defect production.

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# Appendices

## *Appendix I List of openZDM NDIs*

**Table 7: List of openZDM NDIs**

| NDI Number | NDI Type | Description |
|---|---|---|
| NDI#0 | X-ray inspection instrument | X-ray inspection technique used in the VDLWEW use case for residual stress detection |
| NDI#1 | Laser line triangulation instrument | Laser line triangulation instrument used in the VDLWEW use case for straightness measurements at low temperature |
| NDI#2 | Vision based instrument | Vision based instrument used in the VDLWEW use case for measuring the product's temperature profile after the induction furnace process |
| NDI#3 | Vision based instrument | Vision based instrument used in the VDLWEW use case for measuring the product's temperature profile after the descaling unit process |
| NDI#4 | Laser line triangulation instrument | Laser line triangulation instrument used in the VDLWEW use case for straightness measurements at high temperature |
| NDI#5 | Laser line triangulation instrument | Laser line triangulation instrument used in the VDLWEW use case for 3D dimension measurements of the product |
| NDI#6 | Vision based instrument | Vision based instrument used in the VDLWEW use case for surface defects detection |
| NDI#7 | X-ray inspection technique | X-ray inspection technique used in the VDLWEW use case for residual stress detection |
| NDI#8 | Laser line triangulation instrument | Portable IoT sensor used in the VWAE use case for gap & flush measurements |
| NDI#9a | Vision based instrument | Vision based instrument used in the VIDRALA use case for glass bottle thickness measurement |
| NDI#9b | Vision based instrument | Vision based instrument used in the VIDRALA use case for glass gob quality assessment |
| NDI#10 | Vision based instrument | Vision based instrument used in the APTIV use case for detection of welding process defects |
| NDI#11 | Vision based instrument | Vision based instrument used in the APTIV use case for welding process monitoring and aesthetical defects detection |

# Appendix II List of openZDM DATs

**Table 8: List of openZDM DATs**

| DAT Number | DAT description |
|---|---|
| DAT#0 | Quality assessment and quality prediction analyzing, e.g., straightness, thickness, and width of the trailing arms in real-time on-premises |
| DAT#1 | AI-based tool for the recommendation of alternative production parameters' configuration |
| DAT#2 | Module for evaluating the environmental impact of manufacturing systems |
| DAT#3 | Provide real-time optimal setpoint configuration mitigating defect probability, maximizing performance, keeping availability, having a feedback mechanism available to the operator |
| DAT#4 | User interface to allow the simulation of new products, helping to identify the probability of defects and provide insights to mitigate them |
| DAT#5 | Dashboards to follow-up the model's accuracy |
| DAT#6 | DAT#6 Use IR images of thermal cameras and rejection thresholds to implement a prediction model for the horizontal distribution of the wall thickness and the quality of the bottles |
| DAT#7 | Process reconfiguration strategy definition with dashboard visualization |
| DAT#8 | Prediction of problems in the rear-end and front-end gap and flush parameters at the end of the body shop |
| DAT#9 | Prediction of the checking points (assembly line) that may fail according to data from previous stations (including body shop) |
| DAT#10 | Analysis of the causes that impact the detected defects |
| DAT#11 | Real-time monitoring the dimensional and gap and flush measurements |
| DAT#12 | Visualize and monitor in real-time key indicators of manufacturing systems in relation to the product quality |
| DAT#13 | AI-based tool for the recommendation of alternative production parameters' configuration |

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