SIEMENS

Insights Hub

Insights Hub Quality Prediction

System Manual

05/2024

Legal information

Warning notice system

This manual contains notices you have to observe in order to ensure your personal safety, as well as to prevent damage to property. The notices referring to your personal safety are highlighted in the manual by a safety alert symbol, notices referring only to property damage have no safety alert symbol. These notices shown below are graded according to the degree of danger.

> ⚠ **DANGER**
>
> indicates that death or severe personal injury **will** result if proper precautions are not taken.

> ⚠ **WARNING**
>
> indicates that death or severe personal injury **may** result if proper precautions are not taken.

> ⚠ **CAUTION**
>
> indicates that minor personal injury can result if proper precautions are not taken.

> **NOTICE**
>
> indicates that property damage can result if proper precautions are not taken.

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>
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We have reviewed the contents of this publication to ensure consistency with the hardware and software described. Since variance cannot be precluded entirely, we cannot guarantee full consistency. However, the information in this publication is reviewed regularly and any necessary corrections are included in subsequent editions.

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Introduction

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1.1 Introduction

Siemens Digital Industries Software announces a new industrial solution "Insights Hub Quality Prediction". This solution combines the benefits of Industrial IoT technology provide by Insights Hub with Machine Learning (ML) technology to predict product quality results based on manufacturing machine data.

Insights Hub Quality Prediction represents a powerful solution for Production Managers, Quality Engineers, Manufacturing Engineers and Machine Operators to perform root cause analysis of the production process and discover complex relationship between production machine parameters and resulting product quality metrics based on historical manufacturing data. The application provides a user-friendly interface and automatic functions for creating, training, and evaluating ML models without requiring extensive knowledge in data science or statistics.
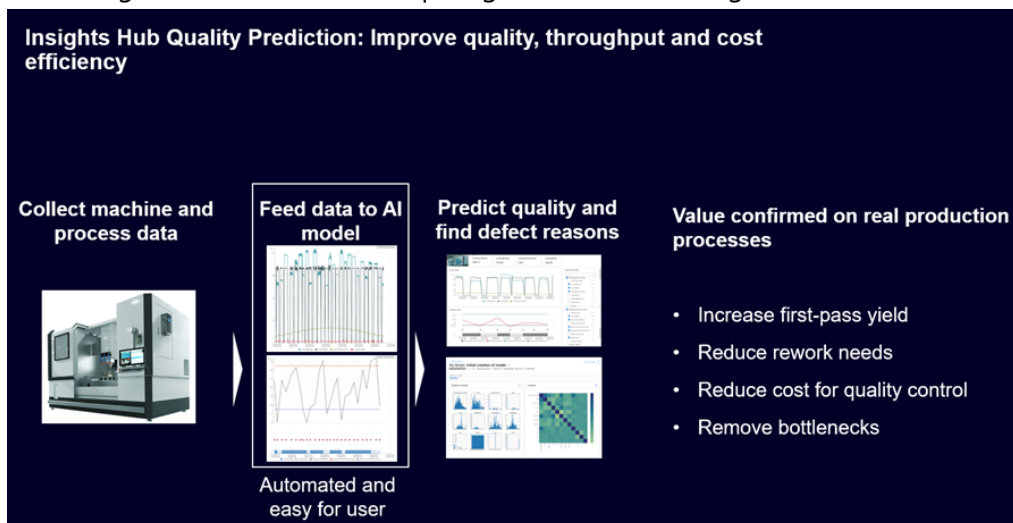

The application's ML model of the process is used to predict resulting product quality in real time with the input of actual manufacturing parameters before a defect and the quality loss. The use of this predictive functionality in the manufacturing process can reduce the number of inspections and measurements, increasing the confidence in product quality conformance.

Quality prediction can be used for active manufacturing process control to take preventive action when quality issues are anticipated in the actual manufacturing conditions.

Implementing reliable quality prediction in the manufacturing process increases productivity and yield lowering overall product manufacturing costs and lead time, with significant monetary and customer satisfaction benefits. It can also reduce the need for manual quality inspection avoiding related capital and operating costs.

The information regarding the prediction model settings and the evaluation of the model results is provided in the video below and the description is explained in document further.

0:00 / 22:37
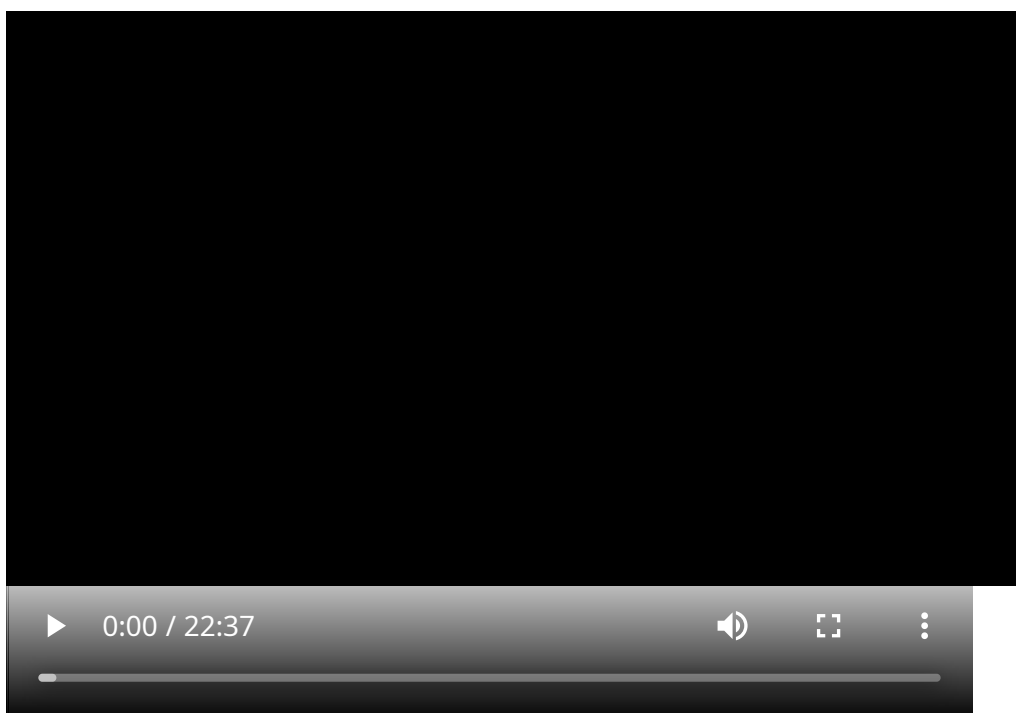
Capabilities

Quality Prediction is a dedicated Insights Hub solution to predict quality parameters for produced goods based on the manufacturing process data. This enables predictive quality improvement by establishing the relationship between relevant manufacturing process parameters and corresponding quality characteristics with implementation of machine learning (ML) approach.
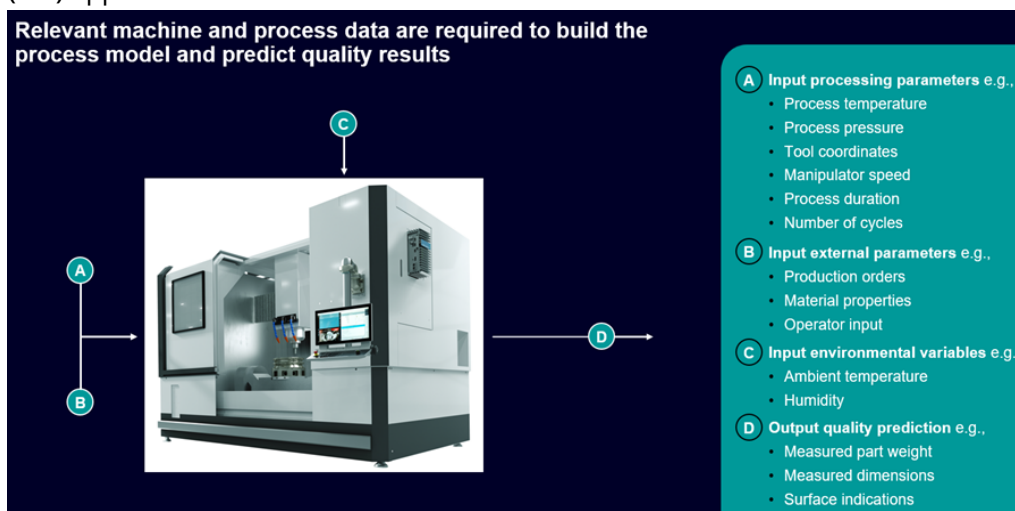
Key capabilities of Quality Prediction Hub are:

• Automatic quality prediction using production data analytics.

- Wizard-based user interface for selecting machine data, quality data and ML model parameters.

- Visualization of machine and quality data, including run-time charts, distribution histograms and correlation map.

- Automatic pre-processing, aggregation, and feature generation for machine and quality data.

- Visualization of aggregated data with run-time charts, distribution histograms and correlation map.

- Automatic training of selected ML model to solve a regression problem for quality prediction.

- Visualization of prediction results with True vs Predicted values chart, Feature Importance diagram and Model Accuracy analysis.

- Automatic update of views for user role engineer and process operator.

- Output of predicted quality results in relation to specified tolerances.
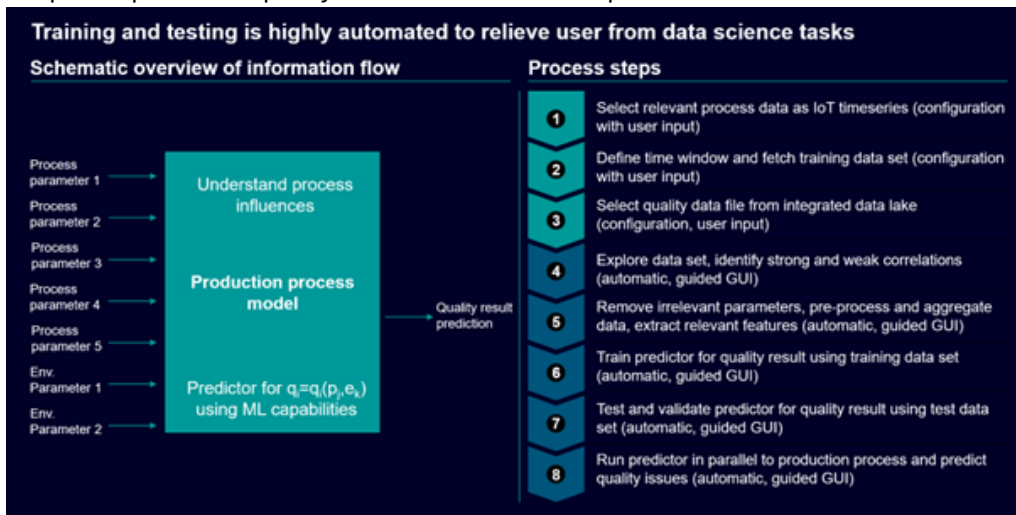
Prerequisites

<div style="text-align: right; font-size: 3em;">2</div>

2.1   Prerequisites

The process data used to train the model must be available as IoT timeseries in a single aspect for the selected asset. To generate effective predictions, the data must be updated with the new data at the same frequency as the historical data used to train the model. The process data must contain following variables:

- **_time (timestamp)** - Variable to define date and time of each data point in IoT timeseries.

- **Input features (double)** - One or more numeric process parameters used as predictors for the process model.

- **Filtering features (integer or string)** - One or more numeric or text process parameters used to define the manufacturing phase.

- **Identifier (string)** - The parameter to identify produced parts is used for the aggregation of process parameters related to each part's manufacturing process phase. This must be same for each data point associated with the selected part and must be unique for all parts.

The quality data used to train the model must be available as a CSV file in the Integrated Data Lake (IDL). This file is extracted from the quality management system used in specific manufacturing process and the file must contain a data table with columns containing the variables listed below:

- **Timestamp (timestamp)** - Variable to define the date and time of the quality measurement result.

- **Identifier (string)** – Variable containing unique serial number of parts.

The values of the identifier should have its counterparts in the Identifiers available in the selected IoT timeseries process data.

- **Target (double)** – Numeric variable containing target quality feature to train the model.

- **Tolerance Low (double)** – Low tolerance limit used for quality acceptance check.

- **Tolerance High (double)** – High tolerance limit used for quality acceptance check.

Additional aspect should be available in the IoT model for a selected asset to store quality prediction results. This aspect should contain variables to store:

- **Target (double)** – Variable to store prediction result.

- **Tolerance Low (double)** – Variable to store low tolerance limit.

- **Tolerance High (double)** – Variable to store high tolerance limit.

- **Identifier (string)** - Variable containing unique serial number of parts. If the Timestamp is used as an Identifier, no additional Identifier variable is required.

These variables must have the same names as the corresponding columns in the quality data file. An example of the IoT data model used to work with the manufacturing process and quality data is shown in the image.

User Rights
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3.1 User Rights

The Insights Hub Quality Prediction application user rights are assigned from "Settings" application. The following user roles determine the user rights:

`mdsp:solution:qualitpredictionhub.engineer` - The engineer should have the following role. Engineer is responsible for setting up the process model including creation and deletion of the models, with a possibility to edit the model parameters.

`mdsp:solution:qualitypredictionhub.operator` - The operator should have the following role. Operator is responsible for the control of the manufacturing process parameters and evaluation of the prediction results for the selected quality parameters.
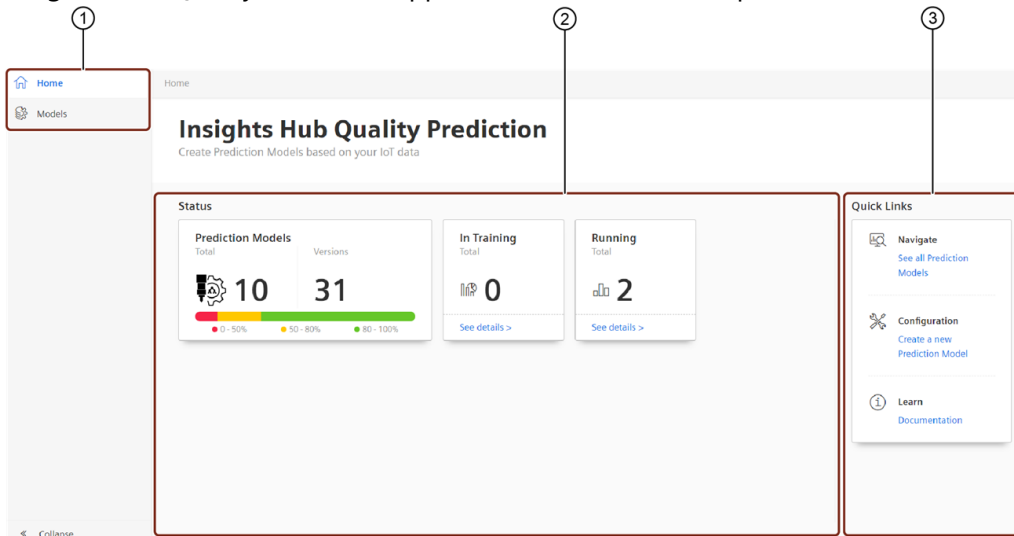
User Interface $\quad$ 4

4.1 User Interface

Insights Hub Quality Prediction application can be accessed from the Insights Hub Launchpad as shown:
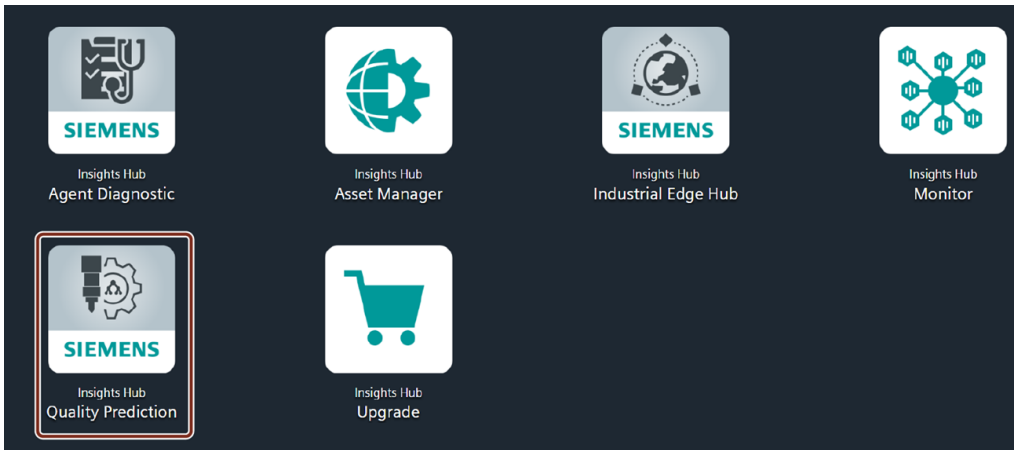
The "Home" screen of Insights Hub Quality Prediction is as shown below when you launch the Insights Hub Quality Prediction application from the Launchpad.

① Navigation tabs

② Displays the total number of prediction models, status, number of "In training" and "Running" models.

③ Quick links

4.2 Prediction Models User Interface

Click the gear icon in the navigation tab and select the "Prediction Models", the following page is displayed.

① Navigation tab

② Available Prediction Models

③ Creates a new model

④ Displays the total number of prediction models

⑤ Displays the following options:

- Stop prediction

- Edit draft

- Training board

- Delete model.

For information on evaluation of prediction results, refer to [Evaluate the Productive Prediction results](#).
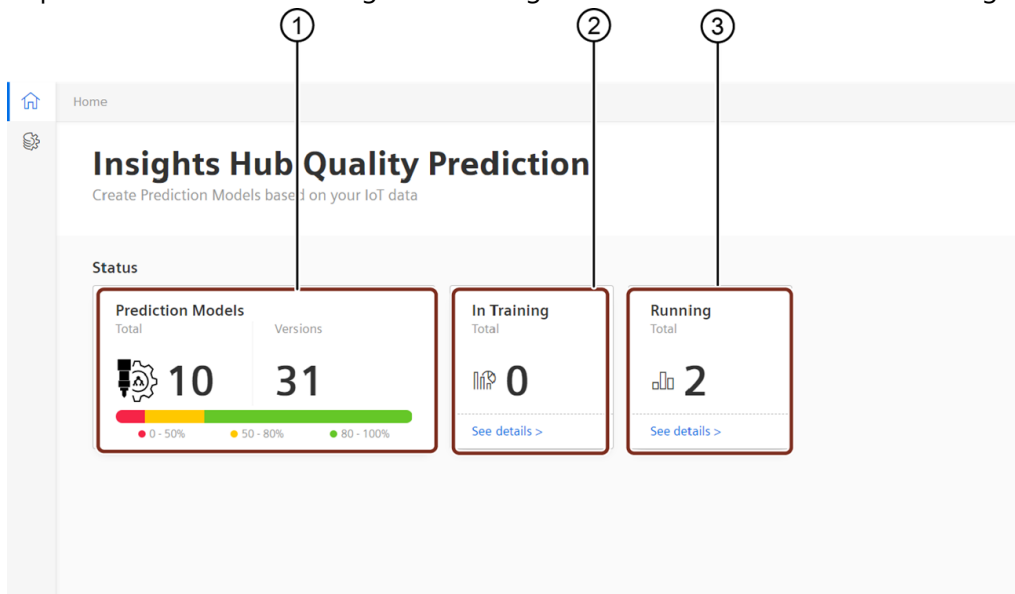
Prediction Models

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5.1 Prediction Models

Overview

The Insights Hub application provides interface and automatic functions to create, train and evaluate data using relevant machine and process data to produce the ML models termed as Prediction models.

The Prediction model initially created is automatically set to status "Draft" and after the successful completion of model training, the model can be stored as a new model version and status is set to "In Training", which is termed as "Training board". If the the model version is set to real-time predictions, the status of the model changes to "Running" and is termed as "Operator Board". the Training and Running models are shown in the below image.

① Prediction Models

② Training Models

③ Running Models

All the available models can be accessed by selecting "See all Prediction Models". "Training and Running" models can be accessed by selecting "See details" for the corresponding model status as shown in the below image.
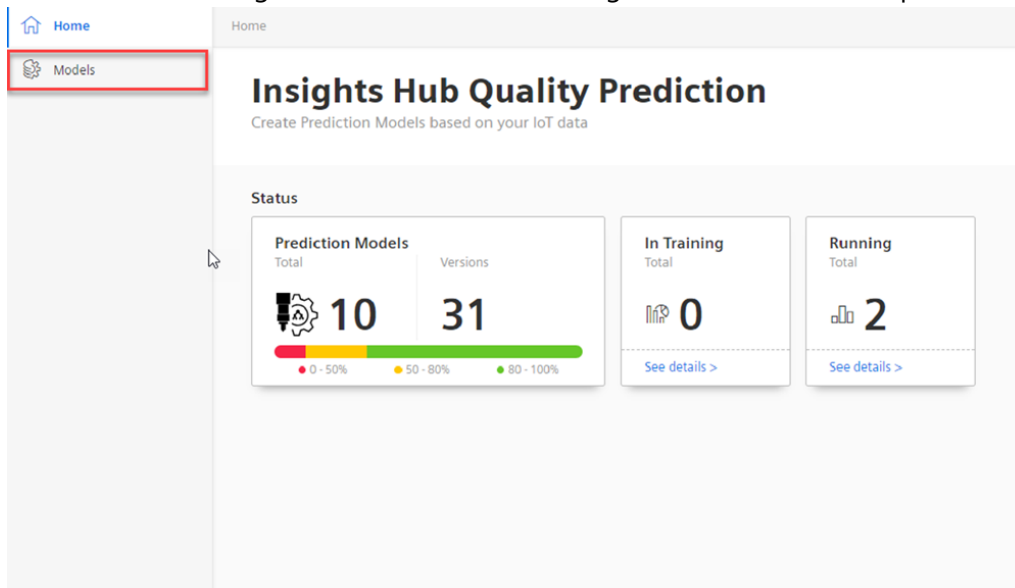
Setup and Analysis of the Prediction models 6
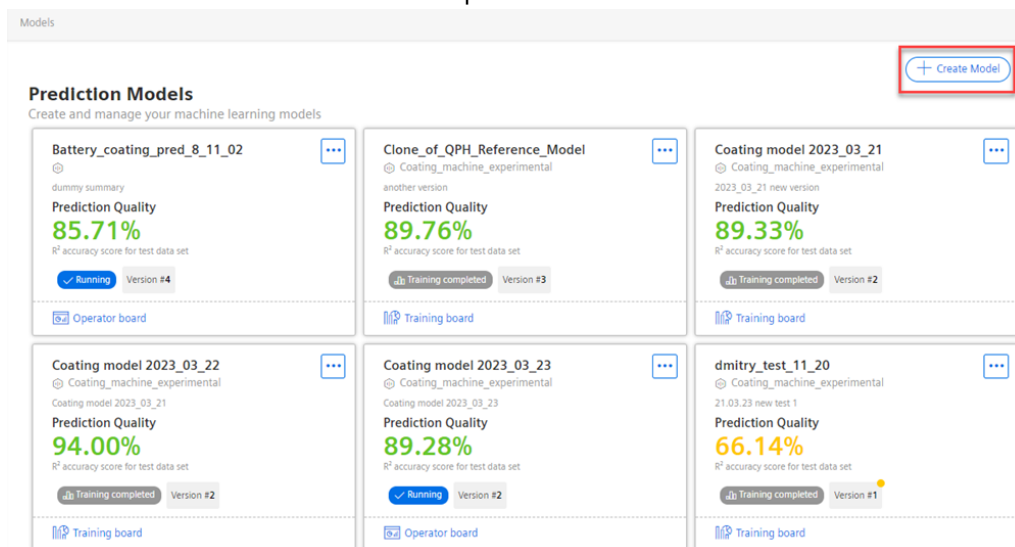
6.1 Create and Edit the models

This chapter describes the steps to generate a model (Training and Operator board) and evaluate the model results.

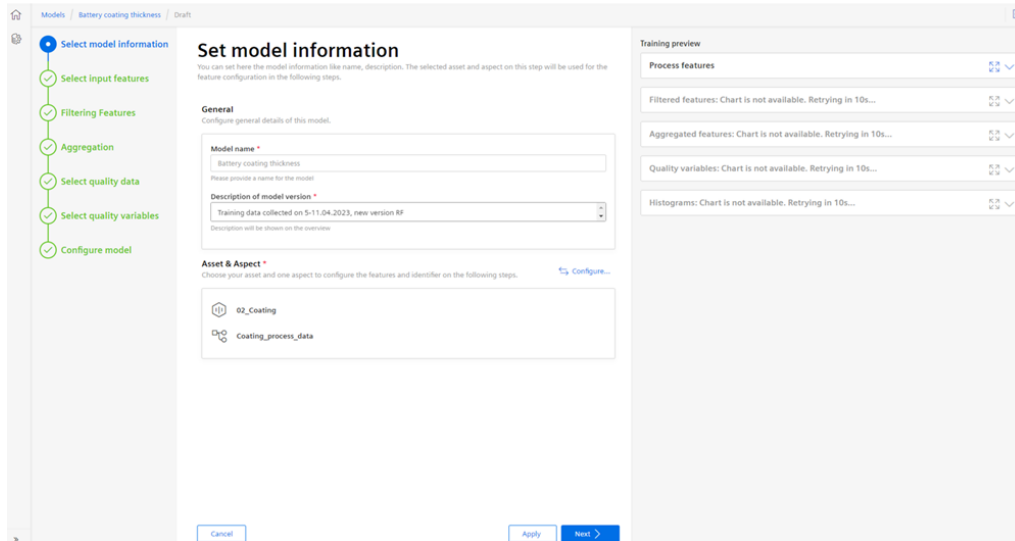To create a Predictive model, follow these steps:

1. From the left navigation, click "Models" to navigate to overview of the prediction models.

2. Click "Create Model" to add a new prediction model.

3.In "Select model information", enter the "Model name" and the "Description of model version". Select the asset and aspect with process data used for model training and click "Next".

4.In "Select input features", choose the time frame to obtain the IoT timeseries process data for training. Select the input variables and enable the additional features toggle. Timestamp can be used as identifier of the parts by selection of the corresponding checkbox.

The data is shown in the chart according to the selected input features on the right-side panel as shown in below image and click "Next".
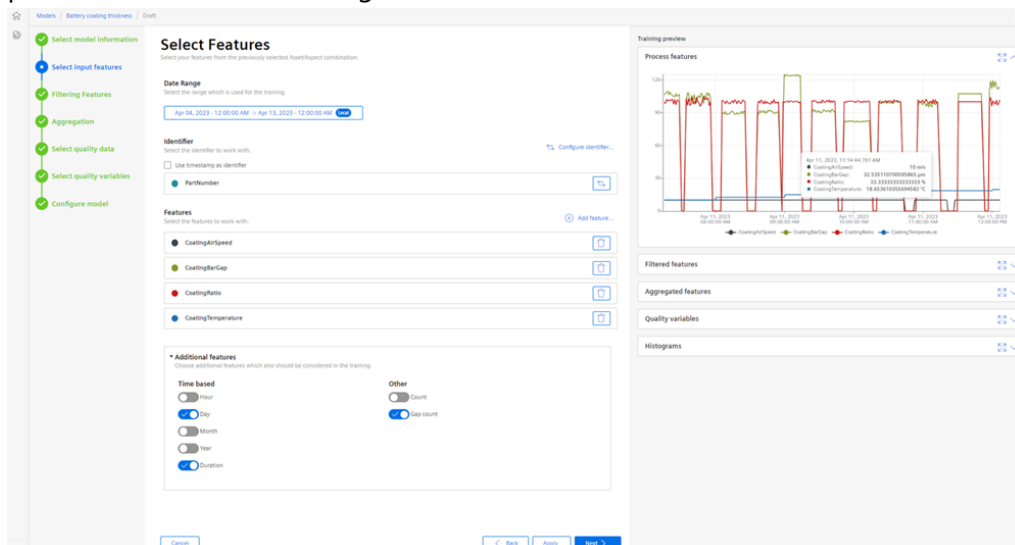
5.In "Select filtering features", add the process variables from the IoT timeseries model with corresponding values to identify the productive manufacturing phase and enable the Zscore filter to remove the outlier values during the manufacturing phase. Multiple filters and variable values can be applied.

Enable filters to select the productive data points (removing idle or non-productive states) and the manufacturing process data points (retaining data for selected machine programmes or operations) and click "Next".

The below image shows the Feature filter options.

6.In "Aggregation", Select "Apply aggregation" to enable the Model Aggregation. Select the calculation methods to build the aggregated variables of the manufacturing phase for each part number and click "Next". Mean, Min, Max and the Standard Deviation can be used to characterize the manufacturing phase.

Select "Remove transients" to exclude first manufacturing phase and the last data points from the aggregation. "Remove transients" is selected if there ia any artificial outliers in the ramp up and ramp down transient phases due to delays in data transfer from the physical machine.

If the process data are already aggregated or single data point is collected during the manufacturing, "Aggregation" is unselected.
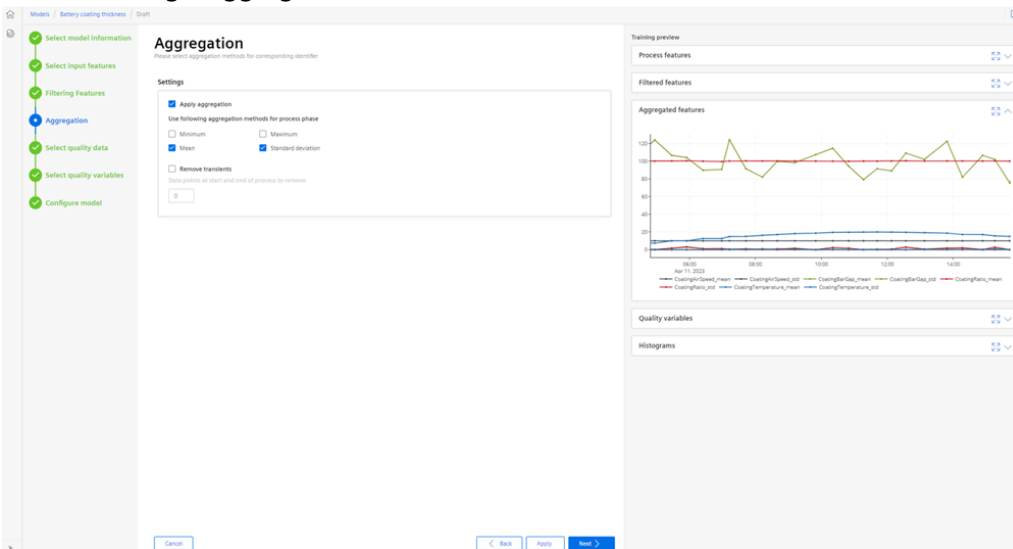
7.In "Select quality data", Select the quality data file in CSV format to train the model from IDL. The quality data file should be uploaded to the selected folder in the IDL by the user. The file must contain defined measurement parameter (prediction target) representing product quality and required variables to be linked to the process parameters for building a process model. Review the file structure and select the feature type for the quality variables and click "Next".
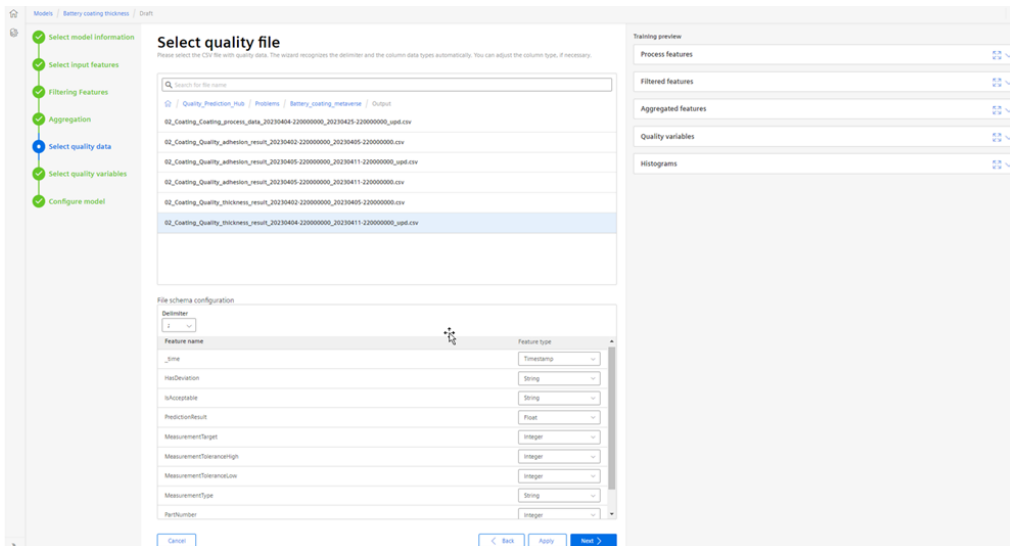
8.In "Select quality variables", Select the quality variables from the quality data file and click "Next".
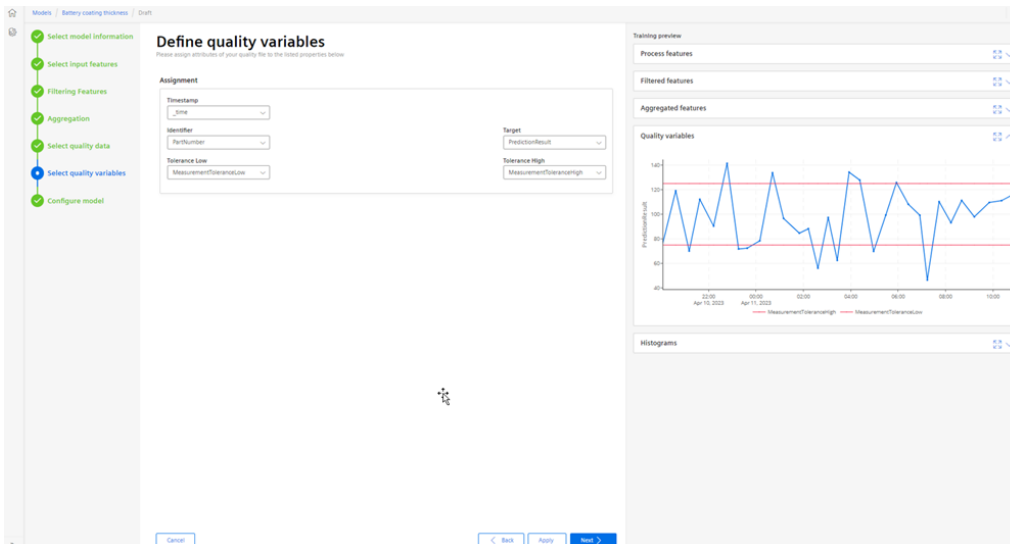
9.In "Configure model", Select the model type and parameters in the user dialog window as shown below. Default model type and optimized parameters are recommended. If "Optimized Parameters" is unselected, the user can enter their own values of ML model parameters.

Click "View Training results" to start a model training. The model status changes to "In Progress" and the user is navigated to the Training Board.
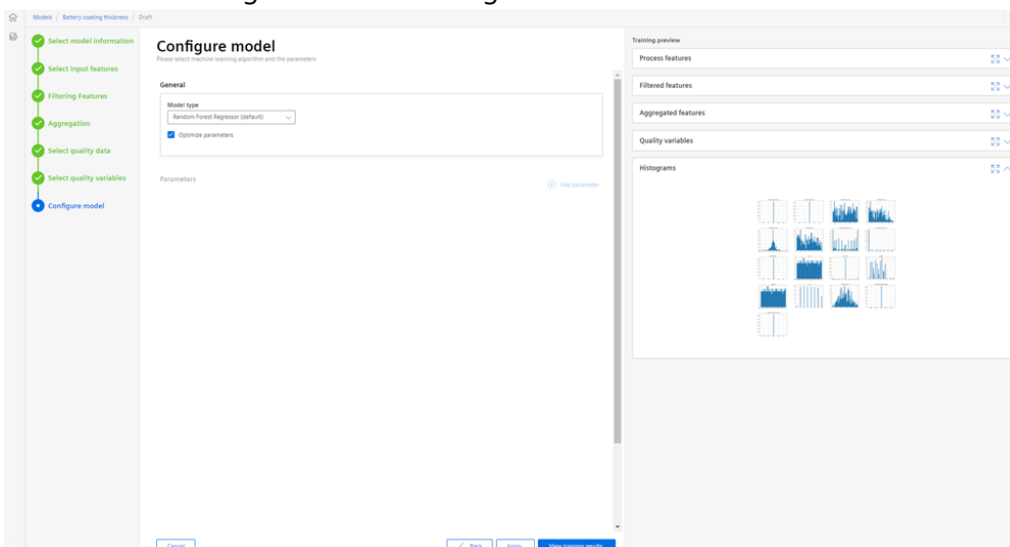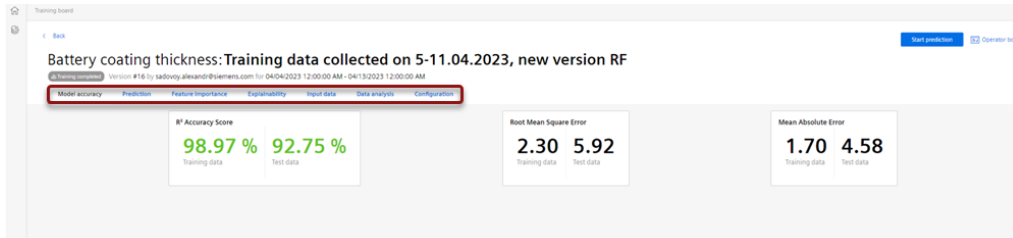
6.2   Evaluate the Model training results

To view and evaluate the training results, follow these steps,

1. Model accuracy

Evaluate the model accuracy with selected metrics with Regression score(R^2), Root Mean Square Error(RMSE) and Mean Absolute Error(MAE) for the training and testing data sets.


Upon completion of the training, the training results is available after a certain period of time. The status of the model changes to "Training Completed".
The model accuracy metrics is represented by the set of characteristics to quantify the quality of the model results aligned to the quality data for the training and testing data sets. The application uses 75% of the overall training data to train the model and remaining 25% to test the model accuracy.

The R^2 accuracy score is a metric that quantifies the correlation between predicted and actual results. The values for the test dataset should be as high as possible, approaching 100% in the ideal case. The root mean square error and mean absolute error describing deviations of the predictions and true results should be as low as possible.

2. Prediction

Navigate to "Prediction" to review the training results.
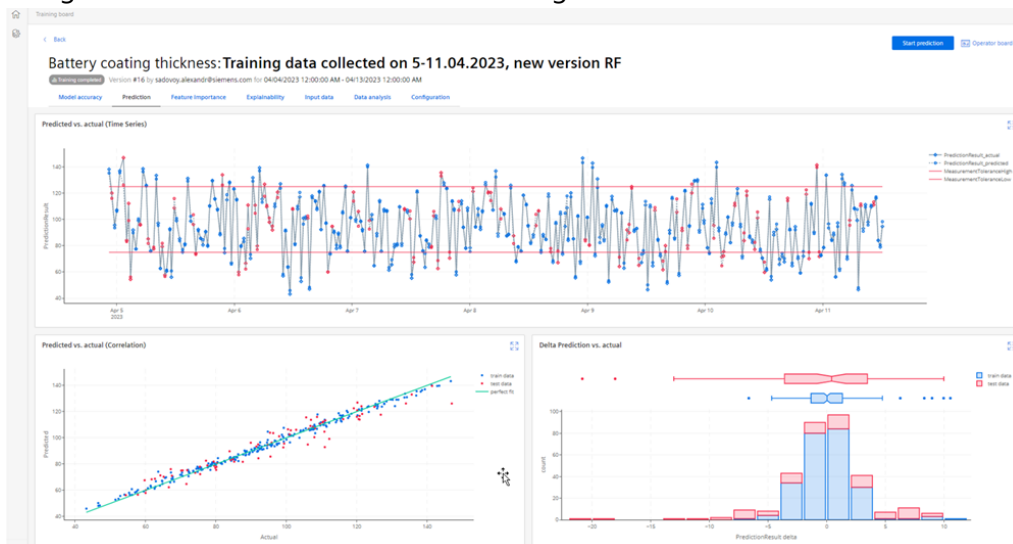
Review the comparison of prediction and true results for the training data set as Runtime chart, Scatter chart and Deviations histogram. The runtime chart displays predicted and actual quality results on a timeline. The correlation between prediction and actual results is visualized at the correlation chart, where each data point should be as close as possible to the green line representing a perfect fit.

The histogram on the chart displays statistical distribution of the deviations of predictions from the actual results. A well-trained model leads to acceptable level of prediction deviation and actual results without critical outliers.

If the accuracy metrics is not sufficient or the model generates too many outliers, Click "Edit" to adjust the model setting. Click "Save as new version" to save model, if the model accuracy and the visual results are acceptable.

Options "Save as new version" and "Edit" are available at the Training Board until the model is in the "Draft" mode.

3. **Feature importance**

Navigate to "Feature Importance" to review the impact of the selected process features on the quality result.

Review the analysis of the feature importance to define the process parameters having the major impact on the predicted quality result.
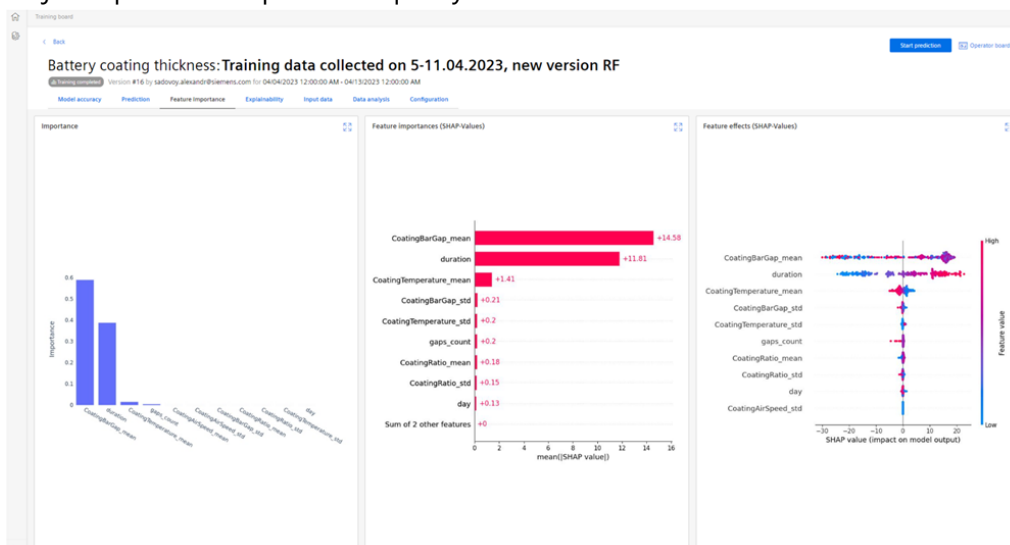
In the above shown image,

Importance chart displays the feature importance obtained by permutation of the input features.

Feature importance (SHAP-values) chart displays SHAP values for each input feature. The SHAP value reflects the how a single feature affects the prediction result. The process parameters with the highest importance and highest SHAP value have the most impact on the quality result. For more information refer evaluation of feature importance.

**Feature effects (SHAP-values)** chart displays the distribution of the SHAP values for each data point in the training data set. The color of the data point represents the feature value and the position on the axis refers to the positive or negative impact on the predicted result.

4. **Explainability**

Navigate to "Explainability" to analyze the impact of the input features on the prediction results.
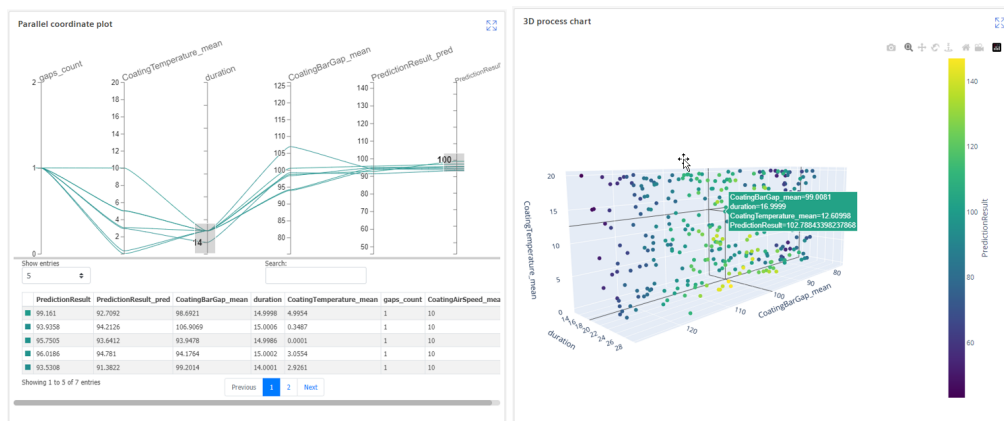
In this section, the Parallel coordinate plot and the 3D Process chart are displayed and these graphs are interactive and enables the user to analyze the dependencies between the input features and the prediction results. This interactive evaluation of Parallel coordinate plot and the 3D Process chart allows the user to find the machine settings to achieve the optimal quality results and are explained below.
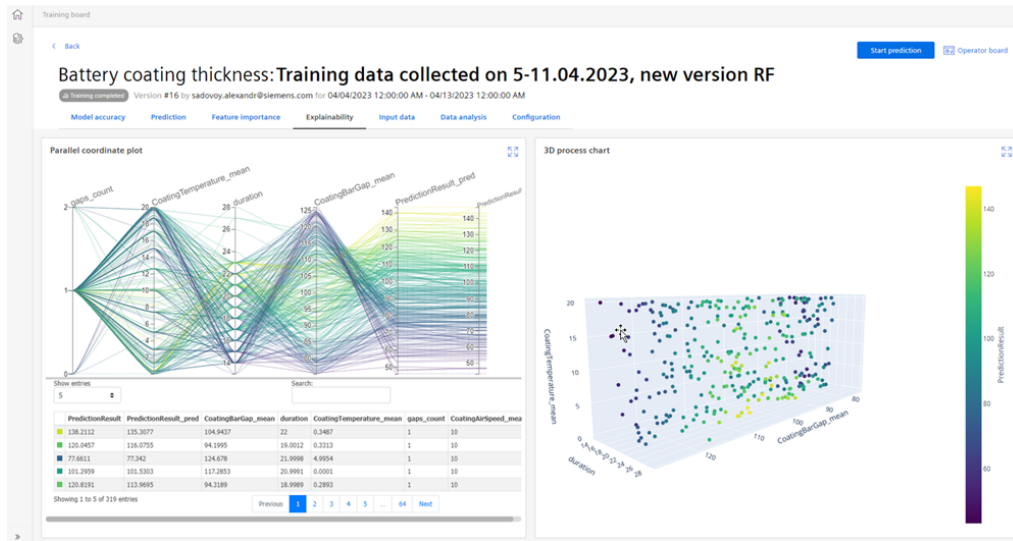
Parallel coordinate plot displays the actual quality parameter values alongside model-generated predictions for the training dataset. It features two right-side axes for this purpose. On the left, the values of the top five input features with the highest importance are displayed. Line color represents quality parameter value (yellow for high, blue for low). The chart allows for immediate assessment of prediction accuracy, horizontal line segments indicate close alignment between predictions and true results, while disparities reveal inaccuracies. It also helps to identify input feature ranges associated with highest and lowest quality parameter values.

3D Process chart displays the training dataset points along three axes, representing the top three important input features. Data point color indicates quality result values. Interactive features like zoom and rotation aid navigation helps the users to focus on specific points of interest and identify locations of highest or lowest values.

The interactive features of the parallel coordinate plot allow users to select datasets with quality parameters in a defined range. By choosing a range on the right axis(representing the target value), users can explore machine settings and input parameters required to achieve the target quality in a specified tolerance. This helps to identify the optimal machine configurations for manufacturing products with quality results at high, low or midpoint tolerance levels. Similarly, selecting a range on the process feature axes enables users to visualize corresponding quality results achievable with the specific machine settings.

5. Input Data

Navigate to "Input Data" to review the graphs of the process features and the quality results.

Proceed with analysis of the process parameters and quality results used for the model training as timeseries charts. The charts visualize the process and quality data used to train the model. The charts are interactive, magnifiable and navigate to functionalities to analyze the data points.

6. Data Analysis

Navigate to "Data Analysis" to analyze the distributions and correlation between the process features and quality result.
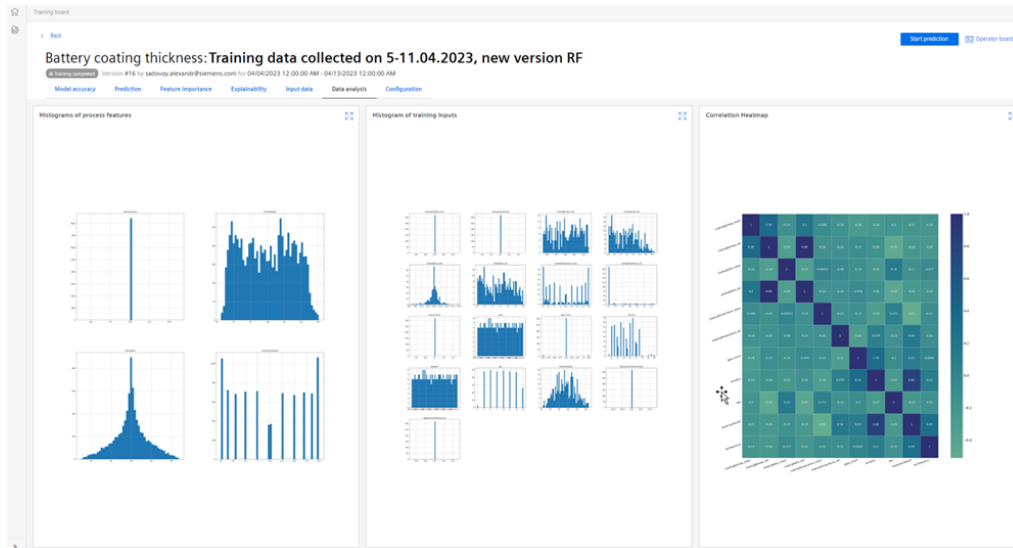

Review the distribution Histograms of the process features, Training inputs (represented by aggregated and additional features) and correlation heatmap showing the Correlation factor for the pair of parameters.

In case of any substantial outliers or unexpected parameter distribution are detected in the distribution charts, it is suggested to edit the model draft or to create new version to remove outliers by corresponding setting in the model setup.

7. Configuration

Navigate to "Configuration" to view the configuration parameters of the ML model.
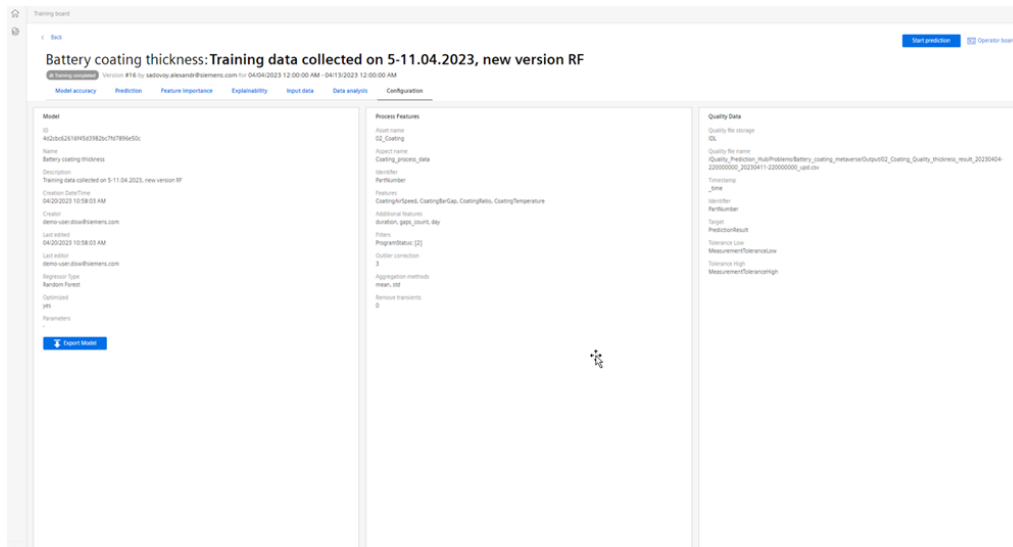
The whole set of the model parameters can be downloaded as a file with the export function.

Generation of Prediction results 7

7.1 Creating Multiple Model versions

Multiple versions of the model can be created with the variation of the Input features, Training time range, ML model types and Parameters. The new draft versions of the model can be created from the "Model Versions" menu as shown in the below image.
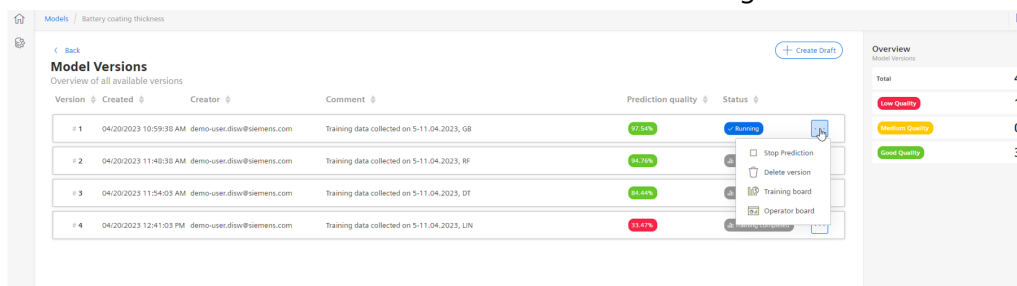
The model with the best prediction quality with highest R2 accuracy score and lowest RSE and MAE errors is selected for the productive usage to generate predictions.

The model versions is created and deleted from the model versions menu. Training Board enables the user to navigate to the Training Board of the actual model version. Start Prediction and Stop Prediction enables the user to start or stop the generation of prediction results.

- **Start or Stop Prediction**: Start Prediction and Stop Prediction enables the user to start or stop the generation of prediction results.

- **Delete version**: The model versions is created and deleted from the model versions menu.

- **Training board**: Training board navigates the user to the Training Board of the actual model version.

7.2 Generation of the model predictions (Inference)

Select the asset and aspect to write prediction results. The result is added to the selected aspect, which should already be available in IoT asset model.

The inference engine will generate predictions of the quality variable used for the training of the model. The destination aspect must contain variables following variables with the same names as in the quality file used to train the model:

Identifier – variable containing unique values representing serial numbers of parts. These values should have counterparts in the identifiers available in the selected process data.

**Target** – variable containing target quality feature to train the model.

Tolerance Low – low tolerance limit used for quality acceptance check.

Tolerance High – high tolerance limit used for quality acceptance check.

Select either one of the following modes of inference,

- **Single point** – Prediction result will be generated at each data point of the selected asset, which meets filtering criteria defining the manufacturing phase used to configure and train the model. The aggregated data used as input for the model to generate prediction will be calculated starting from the first data point of the manufacturing phase.

- **Aggregation** – The aggregated data will be calculated only one time after completion of the manufacturing phase.

To display the prediction configuration dialog window in the model versions overview, click "Start Prediction".
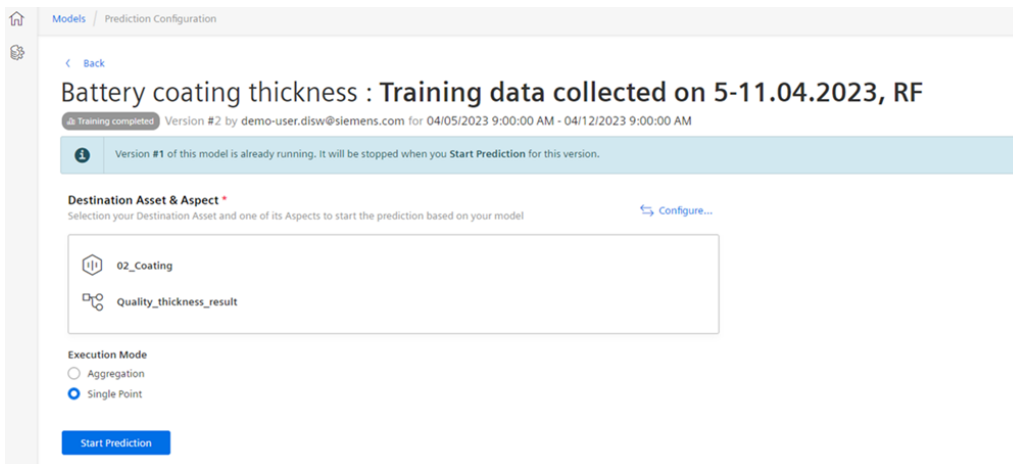
7.3 Evaluate the Productive Prediction results

The Operator Board displays the timeseries chart of the prediction quality result compared with the tolerance limits and synchronized chart of the process parameters. The process and quality prediction variables defined in the model configuration is selected and displayed on the dashboard.

"Operator Board" is accessible from the model versions overview. Operator Board evaluates current production parameters in the context of predicted quality results.

Further variables are selected from the corresponding process and quality aspects by selecting the parameters.

Current prediction result and current values of the process parameters are displayed automatically as indicators on top of the page. The prediction result value indicated is in green, if the result stays within the tolerance limit or red, if the value is beyond the tolerance limit during the production phase of the manufacturing process.

The predicted value is displayed as "N/A" if the process is in the non-productive phase.