

Through-Process Quality Control (TPQC): Latest developments, benefits, and successes

This article presents the Through-Process Quality Control (TPQC) System and Through-Process Optimization (TPO) Services from Primetals Technologies, which integrate domain knowledge, software, and automation expertise to assist steel producers in achieving operational excellence. TPQC collects high-resolution process and product data from the entire production route, providing actionable visualizations, assisting quality assurance, allowing data analytics and artificial intelligence techniques to optimize processes and products, and developing new steel grades on time.

The article also highlights the importance of using rules to support users with root cause analysis and quality decisions. TPO Services can be provided by domain experts who analyze the entire production process, identifying improvement areas to increase efficiency, productivity and quality while reducing waste and costs. The goal is to maintain and enhance product quality, grow and digitalize operational knowhow, increase profitability and better meet customer needs.

The article also discusses enhancements to TPQC, including upgraded Statistical Process Control (SPC) functionality that maintains a log of changes and measures taken during production and digital guidance for selecting appropriate measures when SPC alarms occur. New features provide extended support for recording, visualizing, and evaluating data related to liquid steel production and for entire campaigns, such as tundish sequences or work roll change campaigns. Prescriptive AI models adapt real-time process parameters to avoid predicted deviations and achieve the desired product quality targets.

Authors: Wolfgang Oberaigner, Klaus Jax, and Norbert Huebner, *Primetals Technologies*

INTRODUCTION

Digitalization aims to achieve excellent levels of operation by establishing innovative, digitally interconnected production facilities. A significant contribution toward the digitalization of steel production is the unique combination of the digital knowledge-based software TPQC (Through-Process Quality Control) and Through-Process Optimization Services (TPO Services).

TPQC enables a new generation of insights and knowledge, based on collected product signals and quality evaluation results, and adds a new level of interconnection for automation systems, by collecting and providing data focused on product and process quality throughout the entire production chain.

TPQC supports users from the shop floor to management levels in their daily tasks by zeroing in on three key areas to achieve quality excellence: data exploration, quality assurance, and analytic insights (*Figure 1*).

TPQC FOCUS TOPICS:

Data Exploration

Collecting continuous high-resolution process data for each product across the entire production chain is crucial to capture production data effectively. The absence of production, product handling, and treatment data could lead to inadequate product signals and inaccurate conclusions. Seamless integration with other systems is essential to ensure through-process and comprehensive datasets.



Fig 1 TPQC focus topics and function overview

The product genealogy function enables navigation through production steps. Several visualizations are also available to drill down to signal details, heatmaps, and product and signal comparisons. Production stability measured by Key Performance Indicators (KPIs) and process capability values reinforces trust in product and process quality. Customized reports and business intelligence dashboards complete the data exploration features.

Quality Assurance

Quality assurance starts with the online evaluation of ongoing order execution. The system’s rules engine enables the development, creation, and maintenance of process and quality rules. These rules are used to generate alarms for real-time recognition of deviations. Prediction models identify correlations and patterns between the input variables and the target product properties and create alarms in case of expected deviations. Rule-based assistance provides recommendations on how to cope with alarms.

These recommendations consider possible root causes and offer corresponding corrective and compensational measures. The system automatically performs product disposition and release, with integrated deviation management functions to handle quality-related issues.

Analytical Insights

Visual analytical insights are provided through heatmaps to display the variance of signals and surface defects on vast amounts of data. Additional root cause analysis is further supported by AI methods to gain new insights.

New prediction models are trained using the data collected and deployed in TPQC for real-time product property forecasts. Before implementing new models, simulation helps evaluate their impact and enables virtual product development. Prescriptive models are trained to provide optimized process parameters to ensure desired quality. These new process parameters can be used in Level 2 automation systems as new setpoints for production.

HOW TPO SERVICES ENHANCES TPQC

TPO Services is broken down into two fundamental areas: implementation services and improvement services.

Implementation services focus on customizing TPQC functions, commissioning and tuning the system, and providing comprehensive training. By customizing TPQC functions, services aim to tailor the functions of TPQC to each plant’s specific situation, needs, and targets. Customized functions can include signal selection and designing template views that best suit the plant’s requirements. →



Fig 2 SPC function within the continuous improvement cycle (offline and online)

IT, technological aspects, and data-based AI models are considered for commissioning and tuning the system. Technological aspects and AI models involve signal checking, setting up product release rules, evaluating KPIs, and setting up Statistical Process Control (SPC) and business intelligence. Finally, a comprehensive training program has been developed to meet the specific requirements of each user target group.

Improvement services aim to improve plant performance continuously. The service team consists of key experts in metallurgical engineering who support physical and metallurgical simulation. Expert support improves operational practices, optimizes processes, and enhances product quality and certification. The team identifies areas for improvement and implements hands-on strategies and on-site training to drive progress. Secondly, product development support is offered. This approach enables the creation of innovative and high-quality products that meet specific needs while saving development costs and time. Finally, monitoring and measuring production efficiency and performance using measurable indicators such as KPIs and process capability indicators are performed.

Ultimately, TPO Services aims to implement the TPQC system and functions optimally to improve business performance with the combined efforts of the plant operation team and experts from Primetals Technologies.

INTEGRATING STATISTICAL PROCESS CONTROL

TPQC is further developed based on new experience and knowledge collected during commissioning from the first project to actual references [1]. SPC is one such improvement. SPC is a quality control technique that monitors and controls processes to ensure consistent and efficient operation. SPC collects and analyzes data regularly to detect any changes in the process that could affect quality. Control limits, established using statistical methods, define the upper and lower limits the process is expected to operate. SPC identifies the root cause of process variations, facilitating improvements in product quality. Corrective action may be taken if the process falls outside these limits, and any actions taken must be documented and monitored for effectiveness.

On top of existing online and offline monitoring, SPC and TPQC have been further improved by the so-called “improvement cycle” (Figure 2). The latest update allows the integration of corrective actions, root cause identification, and implementation of measures to monitor progress, such as the effectiveness of process changes, or improvements. Alarms are addressed to responsible team members to set specific actions and enter new root causes into the system. For many standards and certifications, event logs are mandatory. They provide a record of all quality-related events occurring during a process. They can also help trace issues to their origin. Combining event logs with SPC charts gives valuable insights into process performance, identifies potential problems early, and supports continuous improvement efforts.

With the new functional extension, the SPC function of TPQC now covers evaluation, forecast and assistance functions and, therefore, the complete improvement cycle. Steel producers benefit from the expertise of Primetals Technologies while implementing the SPC improvement cycle. TPO Services guide the steel producer through selecting monitoring charts, possible root causes, and events to be recorded in the form of event logs.

EXTENSION OF VISUALIZATION SCOPE IN TPQC

Within the Data Exploration focus of TPQC, the product signals in the form of a time series, or positional data across the entire production

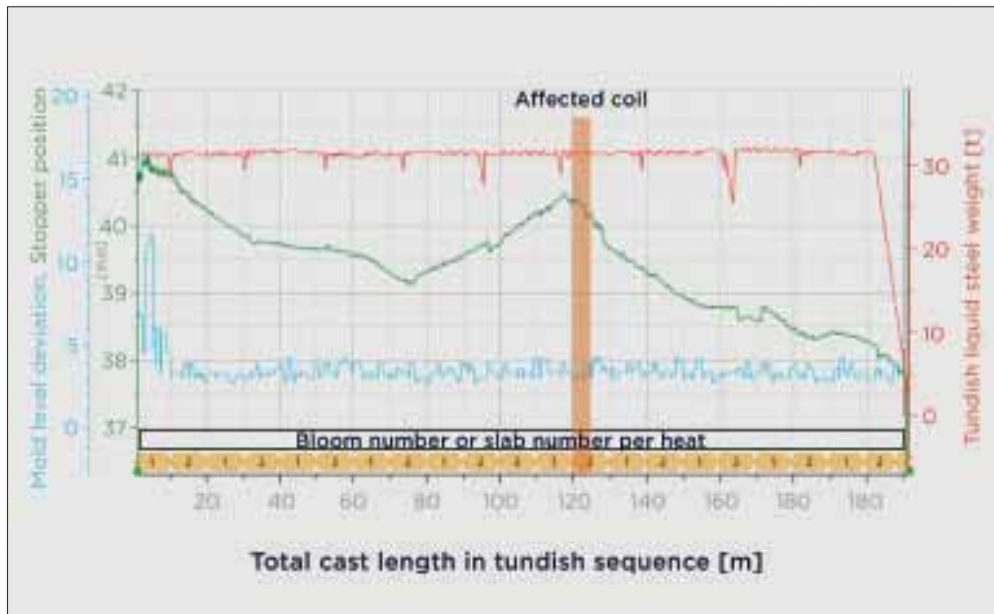


Fig 3 Visualization of a caster tundish sequence at a single-strand

chain are visualized. Visualizations let users compare signals projected onto product positions, such as CCM mold level and FM exit temperature. TPQC has been updated with a new feature that allows users to view data for a selected product in the context of other related products in one chart. This new feature allows us to compare data for the selected product with other products, for example, those produced in the same tundish. Product defects, or deviations can often be attributed to a shared history in the production process. For instance, coils with defects may have all been produced during the same caster sequence, or hot strip mill work roll campaign. By visualizing these coils on the running order of the production unit, it may be possible to gain insights into how, when, and why a defect occurred.

VISUALIZATION OF PRODUCTS FROM SPECIFIC CAMPAIGNS

In a production facility, products are usually produced in distinct campaigns, for example, tundish sequences at slab casters, or work roll change campaigns at hot strip mills. The new chart allows the campaign to be displayed as joint positional product data in high resolution across the entire length produced within this period (Figure 3). This feature can analyze caster tundish stopper position during a campaign and investigate specific events during

a tundish sequence. The projection feature of TPQC also allows the user to view downstream signals projected back to a caster sequence. The projection to a caster sequence allows the final product defects to be traced back to a specific position within the casting sequence.

VISUALIZATION OF RELATED PRODUCTS

Another chart allows users to define specific similarity criteria, such as heat, caster sequence, and work roll campaign. Once the criteria are customized, all products that share a joint relationship based on the selected criteria will be visualized, considering their production sequence, which is visualized as a single value per signal for each product (Figure 4).

Examples of similarity criteria or aggregation:

- Comparing heats from the same tundish sequence.
- Showing products from the first or last ladle in a sequence.
- Displaying all products from the same work roll campaign at a hot strip mill.
- Showing all products produced with the same skin pass mill work roll.

VISUALIZATION OF HISTOGRAM CHARTS

The histogram chart feature allows users to generate histograms of signals for products →

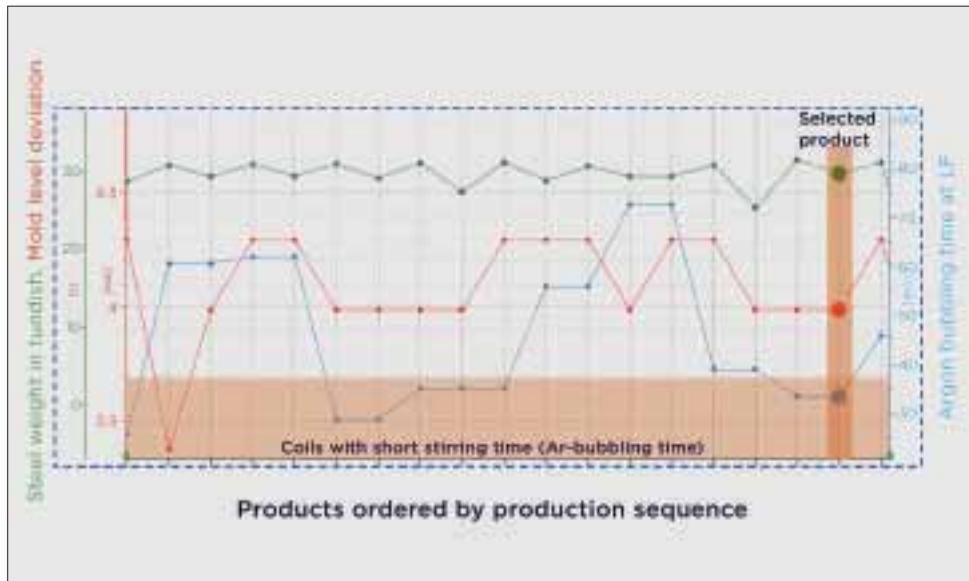


Fig 4 Example for visualization of selected and related products from production history, the big data point represents the selected product

sharing standard filter criteria. The feature can be used to identify patterns in signal distribution. The value measured for the selected product is indicated in the histogram, which reveals its relation to the overall distribution (Figure 5). The function allows for multiple visualization dimensions in one layout, providing advanced filter and aggregation options and new insights.

APPLICATION OF DATA ANALYTICS

Data is an asset. Data analytics can help identify trends and draw conclusions from information. In steel production, a significant amount of data is generated. Once collected, the data must be integrated and checked for quality issues such as outliers, errors, and duplicate entries that could impact the accuracy of analytics applications. The data analytics concept applied by Primetals Technologies begins with statistics, reports, and business intelligence, followed by diagnostics and prediction of mechanical properties (Quality Guard) and virtual optimization (Quality Lab).

Ultimately, prescriptive optimization of critical process parameters for better quality can help increase revenue, improve operational efficiency, and boost business performance. Data-based root cause analytics is enforced in TPQC by easy access and connection via the AI framework, enabling easy model training

and updates. Predictive values, such as those related to mechanical properties, are predicted in Quality Guard and tracked and stored in the mill's data storage and processing system, such as TPQC.

Quality Lab is a virtual simulation environment that operates independently from daily production. It serves as a tool for product developers and quality and production engineers to investigate the effects of different scenarios and optimize product development within known production parameters by adjusting one or more parameters in multivariate charts. With its user-friendly interface, Quality Lab aids in identifying cost saving opportunities and finding stable process windows. It can also be used to enhance new steel grades. Evaluation and setup functions are available to support various users.

BENEFITS

- Immediate response to quality issues, allowing for prompt corrective action.
- Increased yield and productivity.
- Improved quality assurance and product safety without additional testing.
- Lower claim rate, repair costs, and response time to deviations.
- Lower the risk of product downgrades by simulating production parameter variations while ensuring customer

requirements are met.

- Savings on alloying costs by reducing or substituting expensive elements.
- Reduced production costs by optimizing temperature cycles.
- Quantify the effect of process variations and investigate process capability.
- Boost product development and continuous improvement.

Quality Guard has a high level of performance predicting mechanical properties. The results meet the standards for product release for a wide range of steel grades. Predicting the properties throughout the entire coil length ensures that the correct quality is maintained to prevent claims and allows operators to respond quickly to any deviations between predicted and required properties, reducing the need to wait for laboratory test results. Property prediction leads to higher yield and cost savings by reducing sampling and testing efforts.

CONCLUSIONS AND OUTLOOK

TPQC functions and TPO Services are continually expanding and evolving to meet the needs of the metals industry, leveraging the benefits of seamless through-process data acquisition. A curious and creative approach towards combining information and AI is essential for future product and process improvement. TPQC functions and new developments are considering these improvements to better support and assist users in their daily business. Interdisciplinary teams from IT, technology, metallurgy, and data analytics ensure tailor-made solutions and services to achieve and improve operational excellence. **MS**

REFERENCE

[1] Grasserbauer K., Rolling Conference, Triest 2022, Italy, "Improving Product and Process Quality in Steel Rolling via Prescriptive Analytics."

Wolfgang Oberaigner, Klaus Jax, and Norbert Huebner are part of the specialists working with TPQC and TPO Services at Primetals Technologies in Austria.

CONTACT:

wolfgang.oberaigner@primetals.com

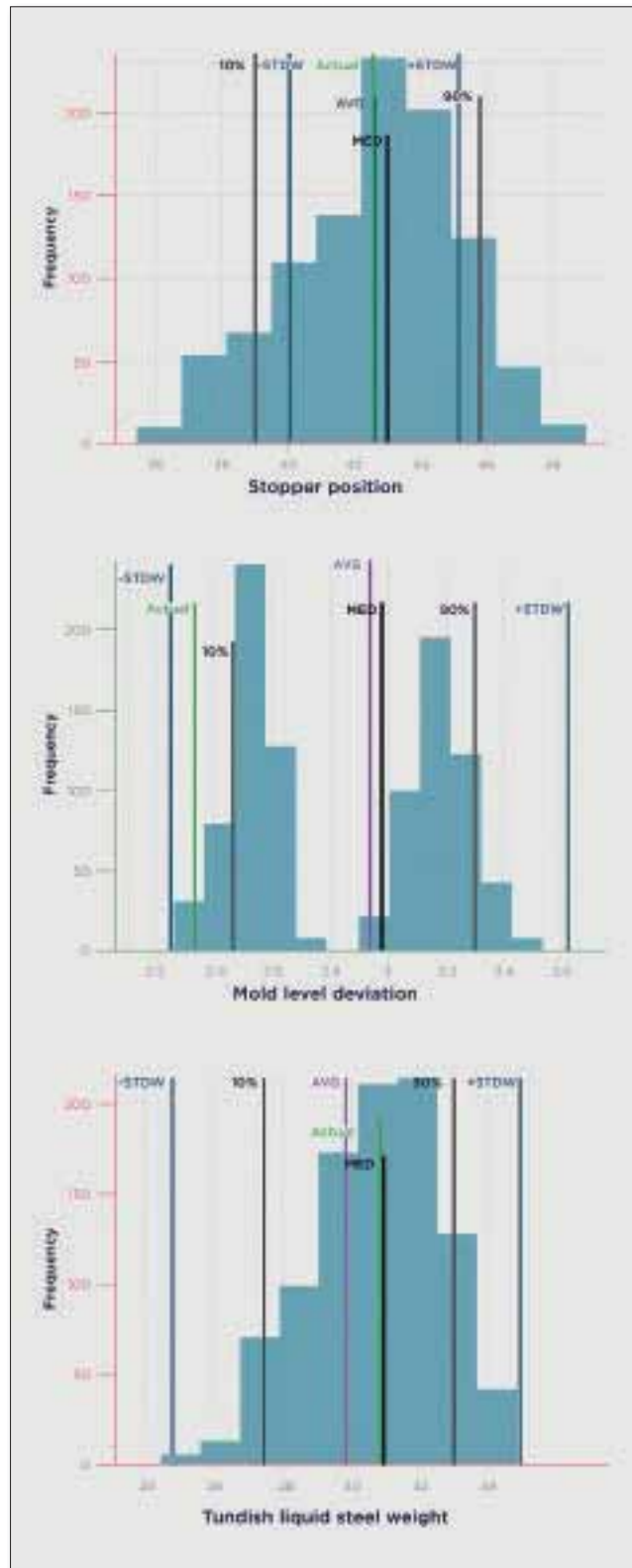


Fig 5 Histogram view for caster signals filtered for the same steel grades produced within the last 10 days