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How Through-Process Optimization (TPO) Assists to Meet Product Quality

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This paper introduces Primetals Technologies' Through-Process Optimization (TPO) Services and Through-Process Quality Control (TPQC) System, 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 visualizations and facilitating quality assurance. It also enables the application of artificial intelligence techniques to optimize processes, accelerate steel grade development, and enhance product quality. The main objective of TPO is to grow and digitize operational know-how, increase profitability, and better meet customer needs. The paper describes the contribution of these systems to achieving operational excellence, with a focus on quality assurance. Transparent and traceable production data is used for manual and automatic quality evaluation, resulting in product quality status and guiding the product disposition process. Deviation management is supported by rule-based and AI-based assistants, along with monitoring, alarming, and reporting functions ensuring early recognition of deviations. Embedded root cause proposals and their corrective and compensatory actions facilitate decision support to maintain product quality. Quality indicators and predictive quality models further enhance the efficiency of the quality assurance process. Utilizing the quality assurance software package, TPQC acts as a "one-truth" platform for product quality key players.

Keywords: *Quality control, Through-process quality assurance, Process optimization, Operational excellence, Data-based AI models*

1. Introduction

Digitalization aims at achieving operational excellence by establishing smart, digitally interconnected production facilities. Primetals Technologies, a leading automation specialist for the steel industry, has developed many solutions fostering digitalization. An important contribution is the unique combination of the digital knowledge-based software TPQC (Through-Process Quality Control) and the Through-Process Optimization Services (TPO Services). TPO Services, tailored to individual customer needs, aim to achieve customers' business objectives in collaboration with Primetals Technologies as a lifecycle partner.

1.1 Through-process quality control software tpqc

1.1.1 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 can lead to inadequate product signals causing inaccurate conclusions. Seamless integration with other systems is essential to ensure through-process data quality. The product genealogy function enables navigation through production steps and, together with the collected through-process data, forms the "Digital Product Twin". Various visualization methods facilitate detailed signal exploration, product comparisons, and monitoring. Production stability measured by indicators such as KPIs(Key performance indicator) and process capability values gains trust in product and process quality. Additionally, report, dashboard, and export functions enhance data exploration capabilities.

1.1.2 Quality assurance

Quality assurance starts with an online evaluation of ongoing order execution. The system's rules engine facilitates the development, creation, and maintenance of process and quality rules; generating real-time alarms for early recognition of deviations. Prediction models identify

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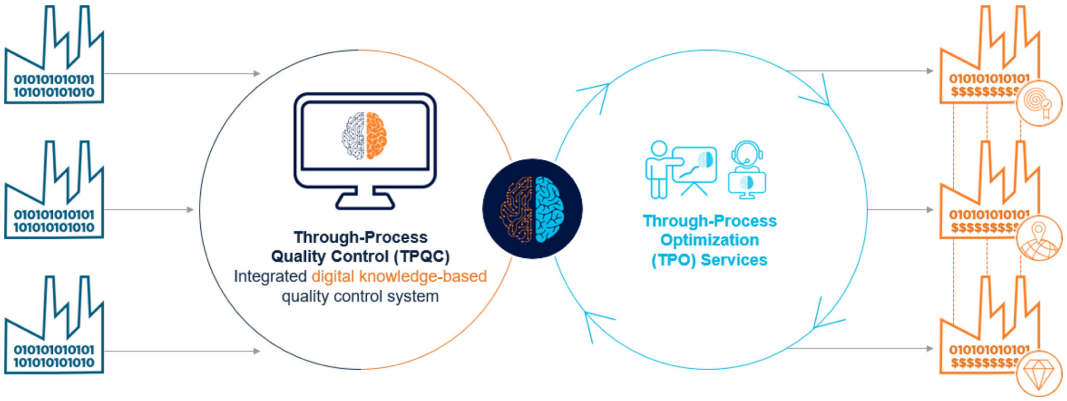


Fig. 1. Interaction of TPQC system and TPO services

TPQC consists of the following software packages:

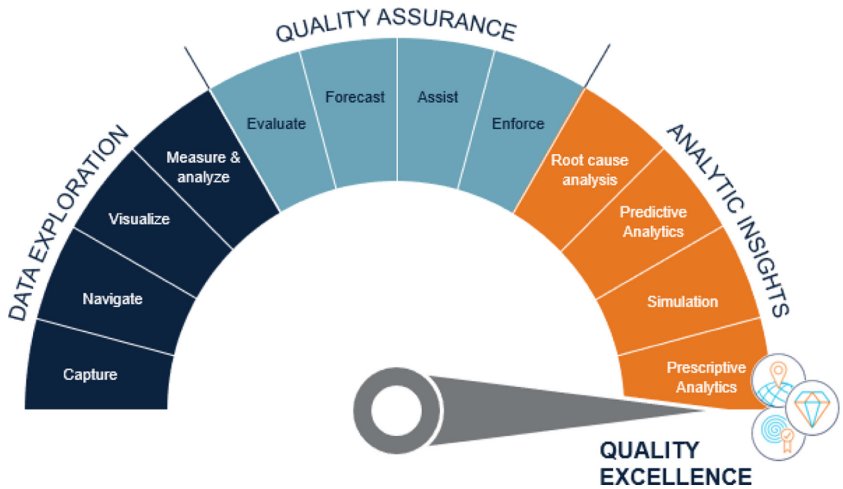


Fig. 2. TPQC software package overview

correlations and patterns between input variables and target product properties, triggering alarms for undetected deviations. Digital assistants provide recommendations to address alarms considering possible root causes and suggesting corresponding corrective and/or compensation actions. The system automatically supports product disposition and release, incorporating deviation management functions to address quality-related issues.

1.1.3 Analytical insights

Visual analytical insights are provided through heatmaps, displaying signal variance and surface defects based on extensive data. AI methods support root cause analysis providing new insights.

New prediction models are trained using the data collected and deployed in TPQC for real-time product property forecast. Before putting new models into operation, simulation helps to evaluate their impact and enables virtual product development. Prescriptive models are trained to provide optimized process parameters to ensure the desired quality. These new process parameters can be used in L2 automation systems as new setpoints for production.

TPQC adds a new level of interconnection of automation systems by collecting and providing data focused on product and process quality throughout the full production chain. It also supports users from the shop floor to management levels for daily tasks. In conclusion, TPQC enables the generation of new insights and knowledge based on collected product signals and quality evaluation results.

1.2 TPO Services

TPO Services aim to implement the TPQC system, and

Fig. 3. TPQC focus topics and TPO Service overview

also to improve the business performance with combined efforts by the plant operation team and Primetals Technologies experts. Primetals Technologies' key expert team consists of domain experts from process technology, data analytics, and IT to ensure operational impact.

Implementation Services focus on three key areas: customizing TPQC functions, commissioning, tuning the system, and providing comprehensive training. In terms of customizing TPQC functions, the services aim to tailor the functions to each plant's specific situation, needs, and targets. The situation, needs, and targets can include signal selection and designed template views that best suit the plant's requirements. IT, technological aspects, and data-based AI models are considered when it comes to commissioning and tuning the system. Tuning the system involves tasks such as signal checking, setting up rules for product release, evaluating KPIs, setting up SPC, dashboards, and digitalizing know-how. Finally, a comprehensive training program is developed to meet the specific requirements of each user target group.

Improvement Services are aimed at continuously improving plant performance.

Technological expert support improves operational practices, optimizes processes, and enhances product quality and certification. The expert team identifies areas for improvement and implements hands-on strategies and on-site training to drive progress. Secondly, product development support is offered. The service team consists of experienced metallurgical key experts supported by physical and metallurgical simulation. This approach enables the creation of innovative and high-quality products that meet specific needs while saving development costs and time. Quality improvement is achieved by monitoring and measuring production efficiency using KPIs and process indices to derive new actions.

Examples of TPO Improvement services for quality assurance

- Surface quality and certification support
- Quality execution and operational know-how services
- Prescriptive process parameter optimization

2. Quality Assurance

Typically, quality assurance ensures product confirmation with specifications, reduces waste/defects, and assists in

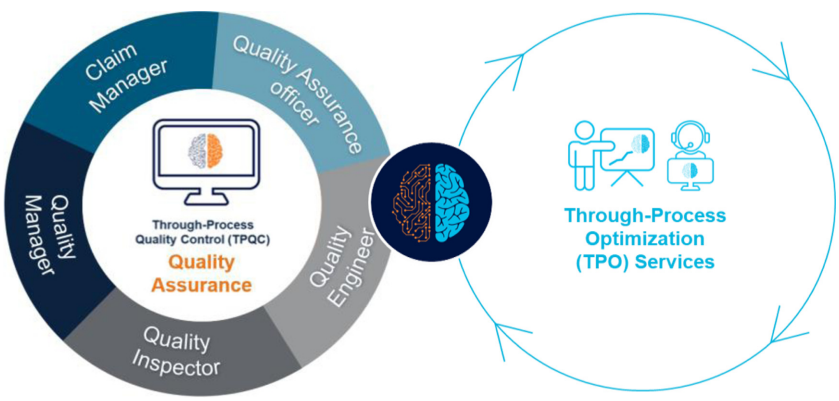


Fig. 4. TPQC Quality Assurance as a platform for product quality key players and corresponding TPO implementation and improvement services

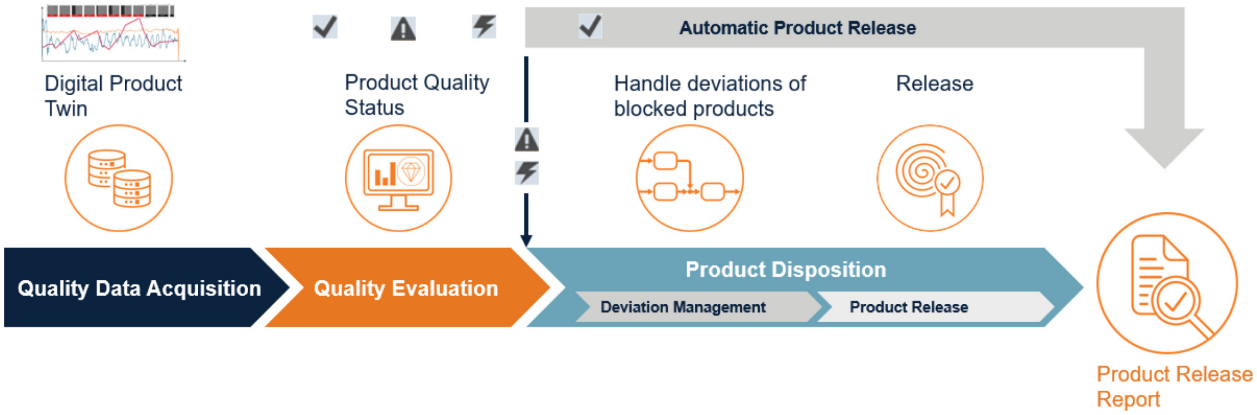


Fig. 5. TPQC quality assurance overview

the avoidance of product faults before they occur. Several steel producers face challenges due to decentralized multiple systems across the steel plant hindering direct communication and automated information exchange among key players in quality assurance. A centralized approach ensures quick response to customer claims and reduction of deviations. By utilizing the know-how embedded in Digital Product Twin, the lack of experienced personnel can be compensated, and critical knowledge is securely stored within the TPQC system.

In TPQC, quality assurance focuses on controlling, evaluating, and enforcing quality in production. The process begins with a rule-based online evaluation of ongoing order execution (material processing). Future deviations are predicted based on real-time property forecasts at intermediate production stages. Various assistance functions, such as Inspector, Operator, and Quality Assistance, provide root cause analysis results, recommendations, corrective actions, and compensation proposals. Furthermore, the system enables enforcement of final product quality through integrated online process optimization, employing statistical process control and prescriptive parameter optimization.

TPQC is aimed to be the one truth system with standardized communication and reporting of production non-conformities. Quality rules can be developed, executed, and updated by authorized quality assurance key players with defined access rights. On-demand TPO Implementation Services can be ordered to ensure the best possible customization and utilization of TPQC functions.

TPO improvement services for quality optimization, inspector training, product release, and continuous improvement process are offered as an add-on.

The quality assurance package enables the ability to change the product quality status. Users can easily edit and add alarms, display surface defect statistics for selected products and modify the confirmation state of root causes.

A key element in quality control for each process unit is the collection of relevant process data and product quality properties. These collected data are compared with admissible limits (threshold values, lower and upper bounds) to ensure that the required quality is met after each process unit, as per the final customer requirements.

The quality assurance process provides a “Product Release Report” containing all details of deviations, actions, event logs and interaction history from the system and its users. This report serves as a comprehensive record of each product’s quality assessment and decision-making process.

Functions from analytical insights furthermore support quality assurance as predictive and prescriptive quality functions. Any calculated, rule-based, or data model-based quality indicators can be integrated into TPQC and used for quality assurance.

2.1 Statistical process control (spc)

Statistical Process Control (SPC) is a quality control technique that monitors and controls a process 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 tolerances that the process is expected to operate at. SPC identifies the root cause of process variations, facilitating improvements in product quality. Corrective action may be taken if the process

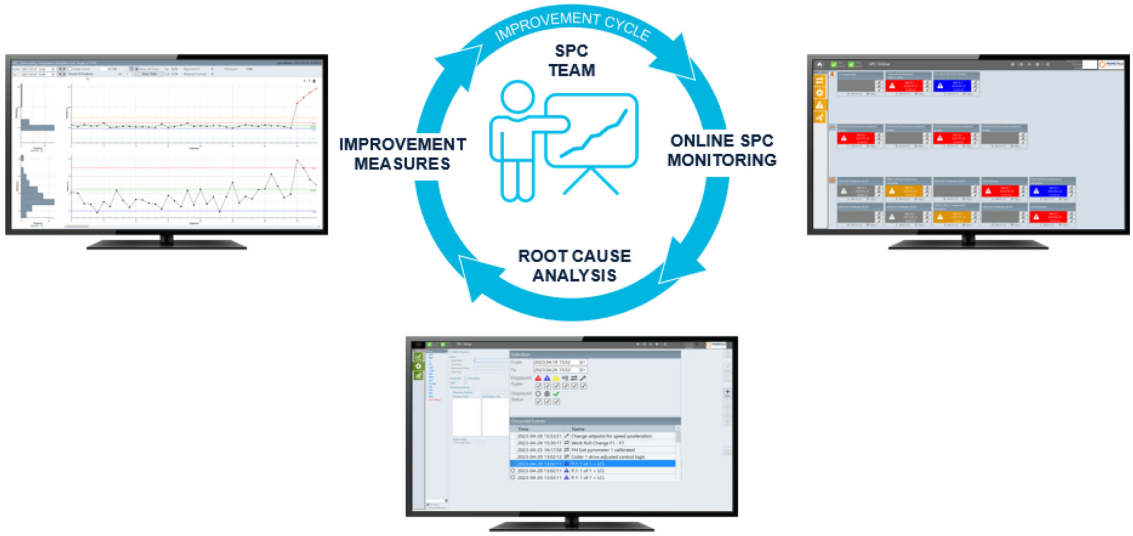


Fig. 6. SPC function within the continuous improvement cycle (offline and online)

falls outside these limits, and any actions taken must be documented and monitored for effectiveness. Therefore, TPQC introduced support for the entire SPC improvement cycle on top of existing SPC online and offline monitoring.

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 identified root causes into the system. For many standards and certifications, event logs are mandatory. Event logs provide a record of all quality-related events occurring during a process. They can also help to trace issues back to their origin. Combining event logs with SPC charts provides 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 Primetals Technologies' expertise while implementing the SPC improvement cycle: TPO Services guide the steel producer through proper selection of monitoring charts, root causes and events to be recorded (event logs).

2.2 Quality Evaluation

Quality evaluation guides the product inspection and performs quality rules by checking the fulfillment of target values and limits. Any deviation in product quality can be identified as early as possible in the process. The system provides automatic product quality status regarding order fulfillment under consideration of all alarms, quality indicators, and prediction results. TPQC provides an online overview of process and quality alarms, including root causes with their corrective and compensation actions.

Fig. 7. Overview of quality evaluation

No deviation detected, quality requirements achieved, and the product may be released automatically to the next production step or shipped to the final customer.

Some process output values are slightly violating tolerances, but no critical violation would result in a direct downgrade. In such cases, the product can be released manually by the quality responsible for the shift or must be put on hold for later review by a quality engineer.

This symbol indicates a severe deviation. The product needs to be blocked. A manual review is required before further processing and the product disposition process is started.

Fig. 8. Data Exploration and Quality Assurance with Quality and Inspector Assistance in TPQC

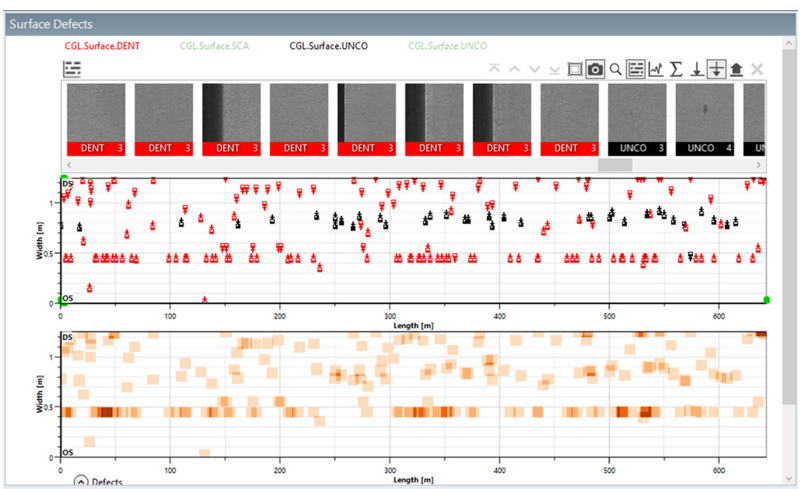


Fig. 9. Inspector Assistance: defect locations and images, defect density, and defect statistics

There are three possible outcomes for product quality status which are indicated by a symbol on the left side of the product ID shown in the TPQC HMI:

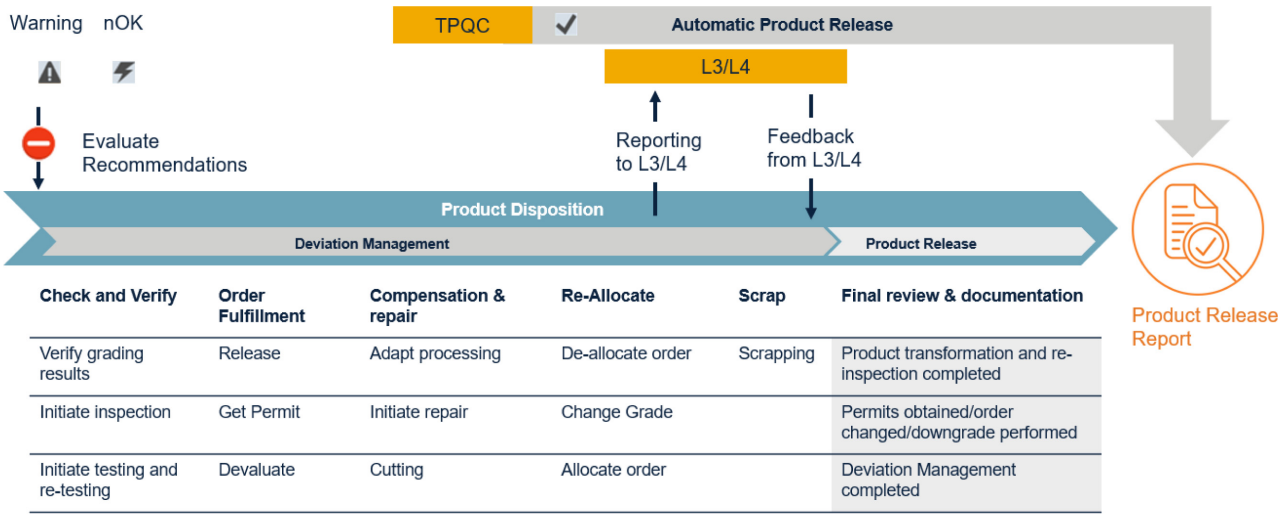
Alarms are categorized into two types whereas process alarms do not directly affect product quality, and quality alarms directly affect product quality (left screen). Alarms are grouped into chemistry, coating, defects, geometry, process, properties, and surface. Detailed alarm signal trends are displayed for each alarm and can be further investigated.

TPQC collects and shows defect pictures of quality-relevant defects depending on their severity.

Defect pictures with significant high severity can be observed and analyzed directly in TPQC, including defect density and statistics. Defects from different production steps can be overlaid and displayed at any production stage, allowing a traceback of defects to their origin. All generated alarms are used in other functionalities of TPQC as well as for reports, dashboards and decision support.

2.3 Product Disposition

Product disposition addresses blocked products with quality alarms. A non-conforming product can be



Check and Verify	Order Fulfillment	Compensation & repair	Re-Allocate	Scrap	Final review & documentation
Verify grading results	Release	Adapt processing	De-allocate order	Scrapping	Product transformation and re-inspection completed
Initiate inspection	Get Permit	Initiate repair	Change Grade		Permits obtained/order changed/downgrade performed
Initiate testing and re-testing	Devaluate	Cutting	Allocate order		Deviation Management completed

Fig. 10. Example of product disposition process

released, blocked, or scraped. If a product is blocked, the system supports the quality engineer to deal with the deviations.

Product release involves documenting the outcomes of deviation management, conducting the final conformance check and re-inspection. It manages and monitors the deviation management process storing all relevant information for reporting. Additionally, it exchanges the captured information with L3/L4 systems. The automatically generated Product Release Report contains key quality information such as a list of nonconformities, a historical log of users and their actions to settle deviations, identified root causes, and release information. The Product Release Report can be used as input for product certification documents, as it largely meets the requirements of ISO 9001 and IATF16949.

3. Conclusions and Outlook

End-customers' demands challenge steel producers to operate at higher quality levels, flexibility, and high production efficiency. Tailor-made steel-grade products, short development times for new steel grades, and zero-defect manufacturing are becoming the norm. Despite the sophisticated L2 and production planning systems in place, quality issues remain difficult to identify and address correctly.

The reason lies in the modern automation system landscape. Each plant is optimized by its isolated systems; optionally, a production planning system is in place to schedule and execute customer orders. Quality monitoring is often left to dedicated inspection systems, which are good at recognizing deviations but limited in executing the product quality. The missing piece in the scattered landscape is an interconnected operational system that collects data from all affected plants with their individual control and inspection systems throughout the production process.

Quality assurance assisted by TPQC acts as a "one-truth" platform for product quality key players.

The system enables stable production on the required quality level and increased production yield by early detection of deviations and automatic and user-assisted deviation management. Such a system reduces the human factor by encoding knowledge into rules and models to be executed manually or used as a digital assistant during operations. The quality management process is improved by reduced manual product inspection, rework and downgrades, and automated product quality conformance checks/grading. Fact-based identification of possible root causes for non-conforming products and recommendations for corrective and compensation actions further reduce the effort for certification processes.

In conclusion, TPQC Software and TPO Services provide a comprehensive framework to meet the ever-increasing demands of the steel industry. It promotes quality excellence, operational efficiency, and customer satisfaction.

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