Integrated Overall Quality Management

Digital technologies are transforming industry at all levels. Steel has the opportunity to lead all heavy industries as an early adopter of specific digital technologies to improve our sustainability and competitiveness. This column is part of AIST's strategy to become the epicenter for steel's digital transformation, by providing a variety of platforms to showcase and disseminate Industry 4.0 knowledge specific for steel manufacturing, from big-picture concepts to specific processes.

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As a general steady development, production processes are becoming more complex while quality is turning from cost (reducing) factor to unique selling point. These are two conflicting requirements because a more complex production situation caused by higher productivity and increasing quality demands leads to a strongly increasing need to control all involved processes.

Similar to how higher flow velocities in a tube cause turbulences, higher productivity may produce uncontrollable complexity (Fig. 1). Optimization of tube properties allows higher flow velocities to keep the laminar flow. In parallel, the manufacturing process has to be stabilized to increase efficiency without losing control. This is the starting point of Industry 4.0 (I4.0) applications such as PSImetals.

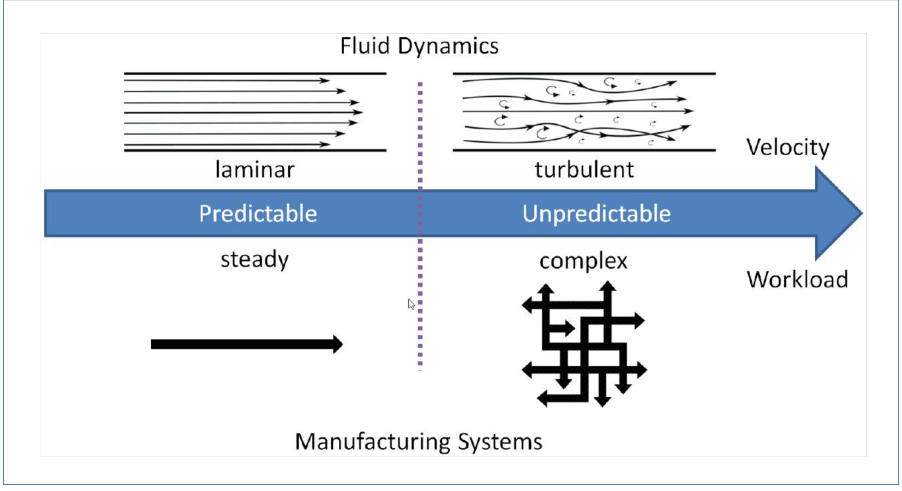
The PSImetals software is an end-to-end approach for the overall supply chain for all the needs of the primary metals industry. It offers powerful and highly configurable standard products to support all processes from planning to execution while respecting the complexity of metal production.[2]

The quality management system (QMS) of PSImetals is embedded into this landscape to interact fully with all other systems and modules in the plant, e.g., planning/scheduling, execution, transport logistics, energy management and so on. All information is based on the PSImetals Factory Model, which can be understood as a "digital twin" of the whole supply chain providing consistent, real-time plant status information.

Quality Management Systems

Prerequisites — Quality standards like IATF 16949 are sometimes referred to as quality management systems. The standards themselves are not the subject of this article. QMS in the sense of this article is a software package to support and

Figure 1



Analogy between fluid flow and manufacturing complexity according to Reference 1.

enable the quality department of a plant to assure the physical quality of the product and the corresponding production processes to fulfill the requirements of standards like the one earlier.

A QMS ensures that the product quality is controlled and improved. It provides tools to the employees in quality management. Other established QMSs often are specialized to the quality topic with the providing company at the same degree of specialization.

But what does it really look like in the plant? Those persons responsible for quality are part of a team that only performs optimally if there is a tight communication among all related units such as production, logistics or accounting. What is required to do so in software?

QMS Integration Into Manufacturing Execution System (MES) — The scope of a modern QMS includes all processes related to quality management:

- Maintenance of quality standards.
- Planning production regarding quality targets.
- Quality data acquisition.
- Monitoring/quality control.
- Non-conformance management.
- Root-cause analysis.

On one hand, QMS is an autonomous and independent system. On the other hand, QMS is part of a complex landscape consisting of different information technology (IT) systems from industrial automation up to MES and enterprise resource planning (ERP). QMS processes are integrated into different business flows and data exchange.

Sales orders from ERP (e.g., SAP) for semi-finished materials as well as for final products are used for the elaboration of detailed quality plans including targets, sampling instructions and test plan (quality planning). Later, quality-related data is received from different sources: laboratories, surface inspection systems, industrial automation (level 2, or LS), sensors, MES, manual input, etc.

Raw data is stored and linked to produced material, including its geometry and production environment (production process, equipment, etc.). Acquired data can be propagated:

- Forward, inherited from parents to children.
- Backward, projected from child to parents, e.g., for root-cause analyses.

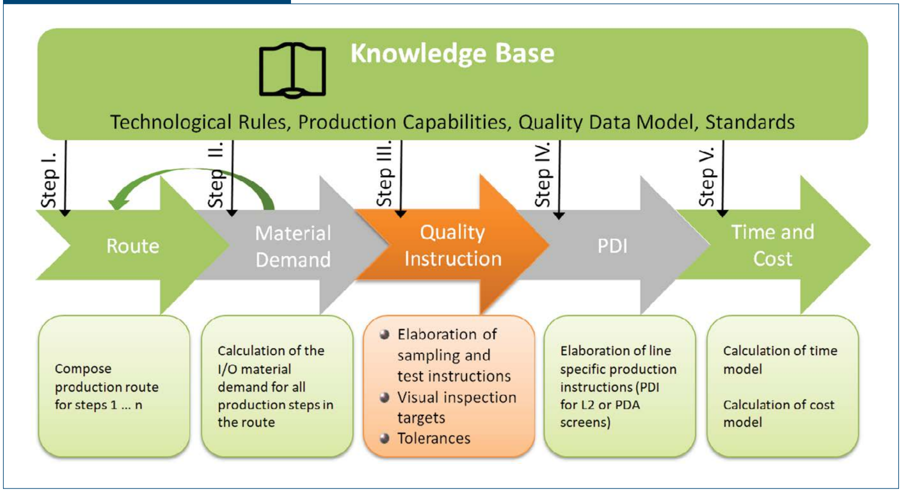
Quality data is used for monitoring and controlling the production situation over the complete plant. QMS reacts on unexpected production results and supports the user to make a correct decision.

If a decision for a considered material is related to changed intermediate or final quality targets, QMS provides support of such activities like regrading, conditional release or reassignment to suitable production order. If a decision is related to keeping quality targets, QMS supports the end user in selecting a suitable rework scenario. But all decisions lead to a changed production situation and require the notification of external systems (ERP/lab/L2, etc.). All quality-relevant events and decisions (like raw material inspections, sampling, material blocking, reassignment of material to production order, final quality decision, etc.) are trackable with the quality journal.

Definition of Quality Targets — The final quality requirements are defined by the customer's specification. In addition referring to existing industrial standards such as ASTM or ISO, special customer requirements (e.g., Si ≤ 0.07% or hardness > 65 HRC) also have to be fulfilled.

Among the elaboration of the necessary production route, the order dressing (OD) function also defines all intermediate quality targets to assure the fulfillment of the customer requirements. Each intermediate quality target is filed into the belonging inspection plan linked to a certain production step (Fig. 2).

Figure 2



Quality elaboration by order dressing, embedded in belonging elaboration of production order.

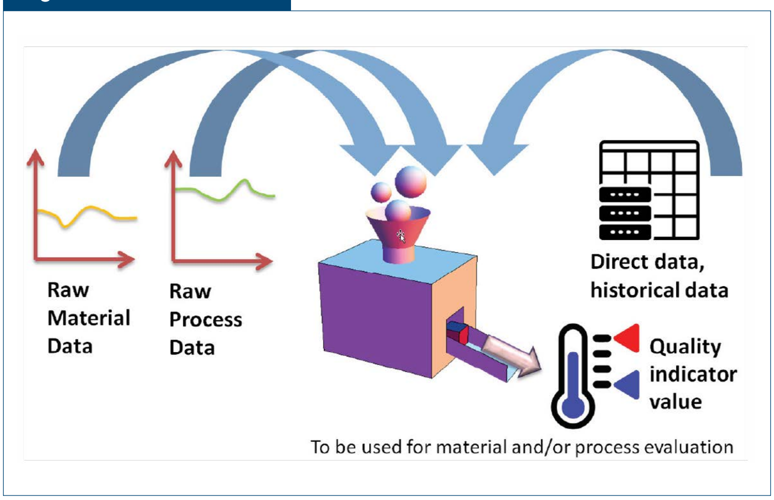
These targets include not only the geometry of the (intermediate) product but also other measures of material properties. Furthermore, OD defines the kind of inspection/test to obtain the appropriate information, including all connected tasks like sample taking and test scheduling. If any quality decision cannot be made out of direct measured data, quality indicators can be defined.

Based on the quality plan elaborated by OD, a QMS decides automatically if production can be continued.

Decisions are made based on rules. In a state-of-the-art QMS, rules are freely definable on how the system should behave under a certain condition.

Rules are defined and maintained by the plant's quality experts. They can be used for the direct comparison of actual values against targets as well as for the calculation of quality indicators (QI).

Figure 3



Quality indicators can be regarded as machines processing arbitrary input to get an indicating value allowing a quality decision.

Quality Indicators — A QI is a measure representing a quality value of a certain material. The QI is based on dependencies between production process data including its setup, input data and output material properties.

QI and test results are used for process and final quality decision (PQD/FQD), determining if the material fulfills the actual quality targets planned for this stage of production (Fig. 3).

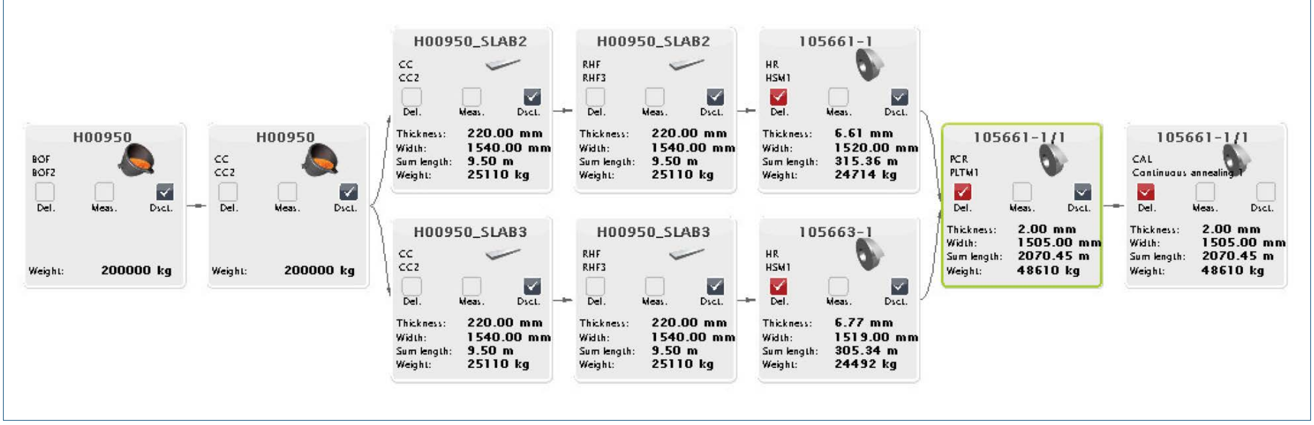
Summing up, QI is defined as a set of rules and functions, fed with arbitrarily complex data to derive a determinable quality value to take a definite quality decision.

While rules in this sense are algorithmic statements, concatenating data from any source, functions derive smaller data sets from mainly raw data (e.g., average, min/max, inclination, etc.). Not only can data from the assigned snapshot (see Fig. 3) be processed, but also data from previous process steps of this material and from previous materials at this process step (or any other data) can be considered.

Overall Quality Control — The materials genealogy (MG) is the backbone for data tracking (Fig. 4). MG nodes represent material transformations through performed production stages. Acquired data is stored as material-related (measurements, defects, test results) and process-related (process parameters). Each data is linked to the dedicated MG node.

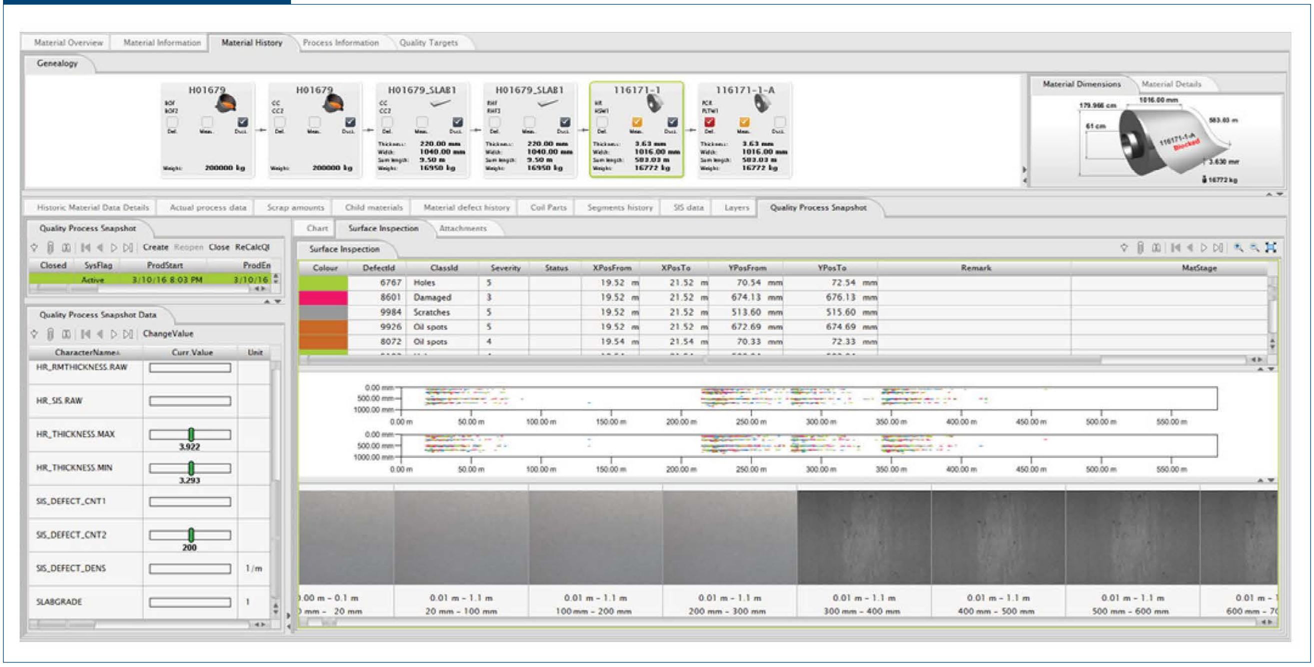
The underlying data structure linked to one MG node is called a "process quality snapshot." Each snapshot is a data container where all quality-relevant data linked to this special material and process step is stored. The data set consists of measured material data and recorded process

Figure 4



Example of PSImetals' materials genealogy.

Figure 5



Example view of the quality process snapshot screen: upper left table shows materials geneaology (MG), upper right: basic material data, lower left: evaluative data, lower right: quality data details (e.g., tables, charts, SIS data and attached pictures).

data. Environmental data and already processed data such as QI are part of the snapshot if this is found to be necessary. A screenshot of the PSImetals process quality snapshot view is shown in Fig. 5.

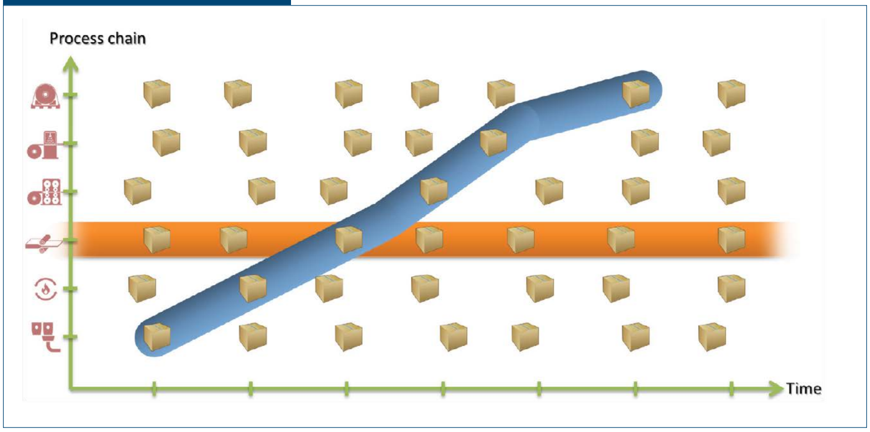
This data structure enables the quality engineer to get access to all recorded quality-relevant data. The data is traceable and trustable because every snapshot is fully versioned. That means all incoming data is stored first in the snapshot. If any signal has to be corrected, either automatically or manually, a new version of the data set is established. In case of, e.g., a customer claim or a product audit, the complete process is transparent and no data modification remains undetected.

The entirety of snapshots not only keeps the production process transparent from the quality point of view, but this data treasure also serves for further actions (Fig. 6).

Statistical Process Control — Statistical process control (SPC) is a well-known method of quality control, applying statistical methods to monitor and control production processes.[3] Transferred into I4.0, SPC consists of a server component and a user interface that enables the engineer to define new views to recognize still unrecovered relations and limits.

SPC is used for monitoring and controlling the production process based on a mathematical model. Depending on quality targets and actual material data, different models have to be applied. If the actual material characteristic does not match quality targets or production process values violate limits

Figure 6



Principle of quality data storage: each material at each (relevant) production step obtains its own data container ("snapshot"), where all recorded data is stored. Data can be used for control of material (blue) and for control of process (orange).

defined by SPC, a material is excluded from production. In this way a QMS supports quality engineers in decision-making.

The SPC server delivers control functions. These rules are used for determining situations when a process is developing in the wrong direction, i.e., a process parameter value moves into an instability zone. The pre-defined control functions can be assigned to control chart at control chart configuration. After calculation of the control chart value, it is checked by assigned control functions and if a violation of any rule is determined, an according failure is generated and stored within the failure log.

Automated Reactions on Quality Issues — The integration of QMS into an I4.0 plant won't be complete if QMS functions only block material and show the actual state to the quality engineer. A fully automated I4.0 plant should make quality decisions by itself not only to prevent defective products from being shipped, but to initiate automated actions to keep the loss as low as possible if any defect of non-conformance is detected.

A fully integrated MES, e.g., with production planning, scheduling and tracking, can show its advantages in managing quality deviations during production. Several different possibilities can be applied in such a case:

- Rework: The easiest way to correct a slight deviation is the repetition of the faulty production step. This action could be appropriate, e.g., in the roughing mill, annealing or trivial if packing was not successful.
- Conditional release: In this case, a correction is possible, but not by only repeating a production step. The future production route of the material has to be adapted to the changed material properties to reach the target quality. If, e.g., the trimming cutter failed, this step can be repeated with different adjustments at a later stage. A faulty section of a strip can be cut out. A slightly wrong thickness after hot rolling is settled by adjusted deformation degree in cold rolling.
- Regrading: If no correction is possible, the last chance to reduce the financial loss caused by scrapping the defect material is to look for other possible fields of application.
  - Is it possible to get a special release from the customer (automated request)?
  - Are there other pending orders this material can satisfy, possibly after processing it? If yes, prioritize with a focus on economic efficiency. Then reschedule automatically.
  - Is it worth storing the material in the yard, waiting for an appropriate order?

Example of Implementation

Even though PSImetals QMS is already installed at many customer sites, the implementation at a major Asian steel producer was a great step forward in I4.0 quality control.

The managed area consists of four different steel plants, one meltshop with two continuous slab casters and one integrated Compact Strip Production (CSP) facility, and another meltshop with three continuous slab casters, two hot strip mills and two cold rolling mills with several annealing and galvanizing lines each.

The following functionalities were implemented:

- Acquisition of process quality data for intermediate and final process quality control, on-line quality decision, and overall quality tracing and analysis.
- Evaluation of the quality situation of each production line to achieve a constant high quality of production.
- Creation of a knowledge database of production and metallurgy for quality design, control and improvement.
- The optimization of production technology and production quality was fulfilled by providing data analysis tools.
- Quality issues are detected in time; the affected intermediate product is disposed to further production.

The number of applied QI within production (Table 1) and the amount of processed data during 3 weeks (Table 2) show that the system already left its pilot phase, showing its suitability for productive use.

Outlook

A fully integrated quality management system doesn't mean that this is the end of the development. There are still many fascinating and necessary things to do. The following is a small selection of functionalities for the near future.

Having the complete quality data set of a plant on hand, an automated root-cause analysis now can be easily implemented to find the vulnerable areas in production when something went wrong. This functionality is almost integrated into the SPC tool and needs only little further development.

Up to now, SPC has been the only tool that can show the right information through a huge amount of process data. The decision of which data is relevant for process control and optimization remains up to the human employee. A new approach will be the combination of SPC with Qualicision®.[4] Here, the algorithm

Table 1

Type and Number of Quality Indicators Per Line, Flat Production

Line type	No. of lines	No. of quality indicators	Typical quality indicator
Continuous caster	3	150	Slab grade; casting speed; basic oxygen furnace end O_2; casting speed deviation; ladle furnace duration; RH add scrap; head/tail slab
Hot strip mill	2	220	Final rolling temperature; coiler temperature; crown hit rate; wedge stability; surface inspection system defect
Pickling and tandem cold rolling mill	1	30	Thickness hit rate; width hit rate; flatness
Continuous annealing line	1	120	Average soaking temperature; surface inspection system defect
Continuous galvanizing line	2	50	Average reheating temperature; coating weight

Table 2

Amount of Processed Data After System Ramp-Up

Parameter / Date	21.10.2019	11.11.2019	Three-week throughput
Common number of stored measurements	3,311,328,806	4,274,627,108	963,298,302
Common number of referenced material states	337,144	370,830	33,686
No. of time-related measurements	131,976,969	145,480,260	13,503,291
No. of length-related measurements	2,959,786,755	3,753,522,810	793,736,055
No. of SIS measurements	172,077,148	207,449,294	35,372,146
No. of stored attachment links to picture	32,422,879	50,877,606	18,454,727

itself finds the relevant data to regard and prevents the user from comparing curves without information retrieval.

Quality prediction based on machine learning is already done in PSI in the frame of a pilot project. In Reference 5, this project is explained in detail.

Conclusions

The advantages of a fully integrated QMS have been shown in this article; the functionality of this kind of system was explained. Summarizing, the state-of-the-art QMS is able to accompany and control a fully automated producing plant regarding latest quality requirements.

References

1. K. Efthymiou et al., “Fluid Dynamics Analogy to Manufacturing Systems,” *42nd CIRP Conference on Manufacturing Systems,* Grenoble, France, 2009.
2. H. Wolf, “The Integrated Production Management System — The Platform for Innovation,” *4th ESTAD,* Düsseldorf, Germany, 2019.
3. E.L. Grant, *Statistical Quality Control,* McGraw-Hill Book Co. Inc., New York, N.Y., USA, 1946.
4. R. Felix, “Multi-Criteria Decision Making (MCDM): Management of Aggregation Complexity Through Fuzzy Interactions Between Goals or Criteria,” *Proceedings of IPMU’08,* 2008.
5. J. Coppe et al., “Machine Learning Based Predictive Quality,” *4th ESTAD,* Düsseldorf, Germany, 2019. ✦

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