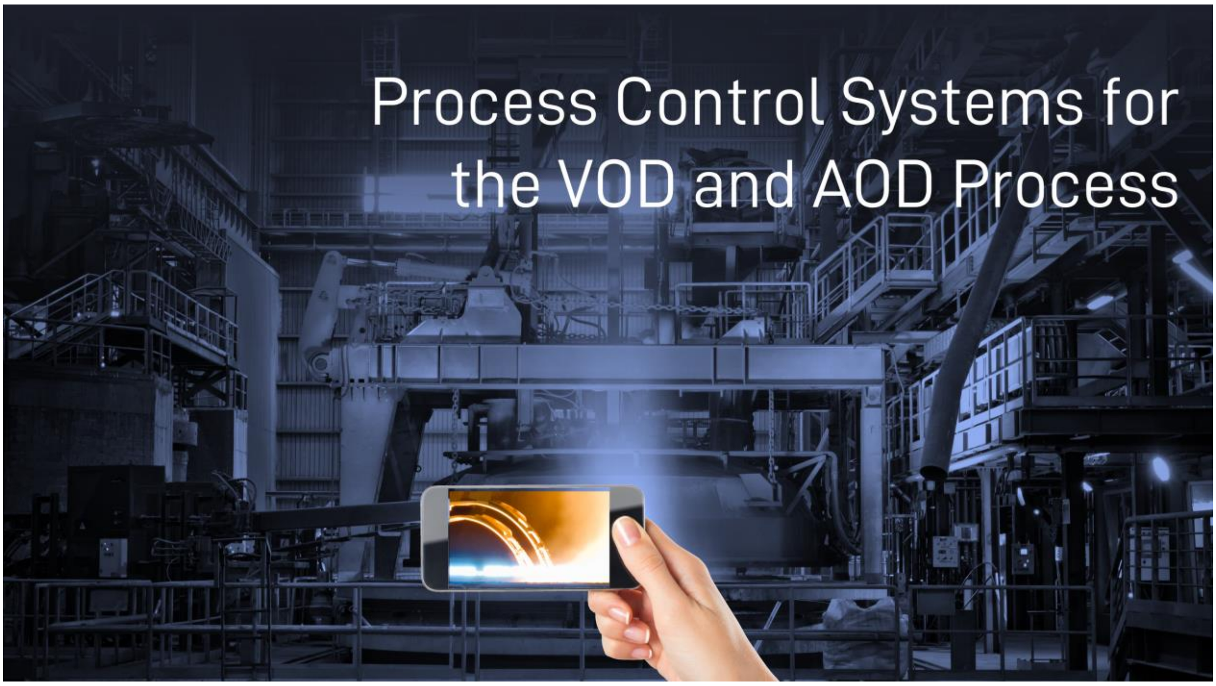
Process Control Systems for the VOD and AOD Process

Robert Pierer and Sebastian Michelic

qoncept dx GmbH, Peter Tunner Str. 19, 8700 Leoben, Austria

This article describes in detail the requirements of a modern software solution to supervise, control and optimize metallurgical processes.

Although this article is dedicated to the AOD and VOD process, it can provide useful information for the entire process industry in abstract form.



1 INTRODUCTION

In Part 1 of the AOD and VOD considerations (*Metallurgical and Economic Considerations of the AOD and VOD Process)* we pointed out that the processing of stainless steel and special steel requires modern mass production with a strong focus on ergonomics and resource efficiency. Both the AOD and VOD processes require an optimized plant configuration and an intelligent process control system with metallurgical models and set-point control. In the present article we give a brief overview of the concept of the automation pyramid and why it should be broken up in the context of Industry 4.0 (chapter 2). Furthermore, the present article introduces the idea of systematization levels (chapter 3) and describes how this approach can be used during requirements engineering (chapter 4.1). Finally, chapter 4.2 summarizes the requirements for a AOD and VOD process control system in more detail.

2 THE PROCESS CONTROL LEVEL

The term Level 2 (as a synonym for process control or process automation), which is frequently used in the steel industry, comes from an attempt to define automation systems with the help of a pyramid, the so-called automation pyramid:

The techniques and systems that combine the data streams for controlling and monitoring the entire manufacturing process are classically classified using the so-called automation pyramid.

The goal of the automation pyramid is to reduce the complexity of industrial manufacturing by dividing the processes of companies into individual levels. Due to the wide range of possible applications and the large scope for interpretation, a large number of variants of the automation pyramid have developed to this day [1]. Often levels are removed in the different models, new ones added or combined. In addition, the names of the levels often differ from one another. The interested reader will find a list of 25 models from the literature in the publication by T. Meudt et. al. [1].

At this point it should also be mentioned that the concept and the architecture models of intelligent manufacturing (Industry 4.0) demand a breakdown of the “strict hierarchy” of the automation pyramid. This breakdown of the individual levels into a network of simple communication should enable an easy and consistent exchange of data and information with regard to product, process and status of the products or processes.

Regardless of whether it is strictly hierarchical or broken down to individual local and fully networked systems, a modern software system for process control must meet functional requirements. The present article therefore dispenses with a subdivision into individual levels and understands a process control system to mean a software system for supervision, control and optimization of metallurgical processes.

3 THE SYSTEMATIZATION LEVELS

The following chapter describes the differences between mechanization and computerization, deals with the current state of the IT landscape in the steel production industry and shows a possibility of systematizing the requirements to be met.

According to Frohm et. al. [2], automation in manufacturing can be seen as two basic classes of automation: mechanization and computerization. The first can be defined as the replacement of human muscle power, such as material and energy transformation. Computerization can be defined as the replacement of cognitive tasks, such as human sensory processes and mental activity. This include collection, storage, analysis and use of information in order to control the process. Thus, computers are implemented into modern manufacturing operations to improve the operators understanding and awareness of the present and future situations (i.e. for optimal performance control).

We know from our experience that the steel industry is characterized by a wide variety of degrees of computerization (i.e. the use of software systems along the levels of the automation pyramid) . In connection with process control systems, the current level of computerization ranges from manual control and manual recording of process data to (partially) fully automatic control including complete digital track and trace applications. Previous developments and solutions for software for the steel industry were strongly driven by monolithic software development. This comes very much from the automation pyramid already mentioned. Depending on the level, there are clear definitions of the functions and the communication between the individual software systems follows a clear hierarchical approach. Despite this clear definition of responsibilities, the functionalities of software systems at different levels of the automation pyramid were repeatedly mixed up. This situation is very often historically shaped and additionally depends on the degree of innovation of the respective company.

The concept of the intelligent factory (often also referred to as intelligent production, smart factory, smart manufacturing, etc.) represents a comprehensive production concept (i.e. always taking into account the entire value creation process). Based on the Industry 4.0 maturity level, the present article suggests the following systematization levels for modern and state-of-the-art process control software systems (see Figure 1). The lower picture of **Figure 1** explains the different levels in more detail.

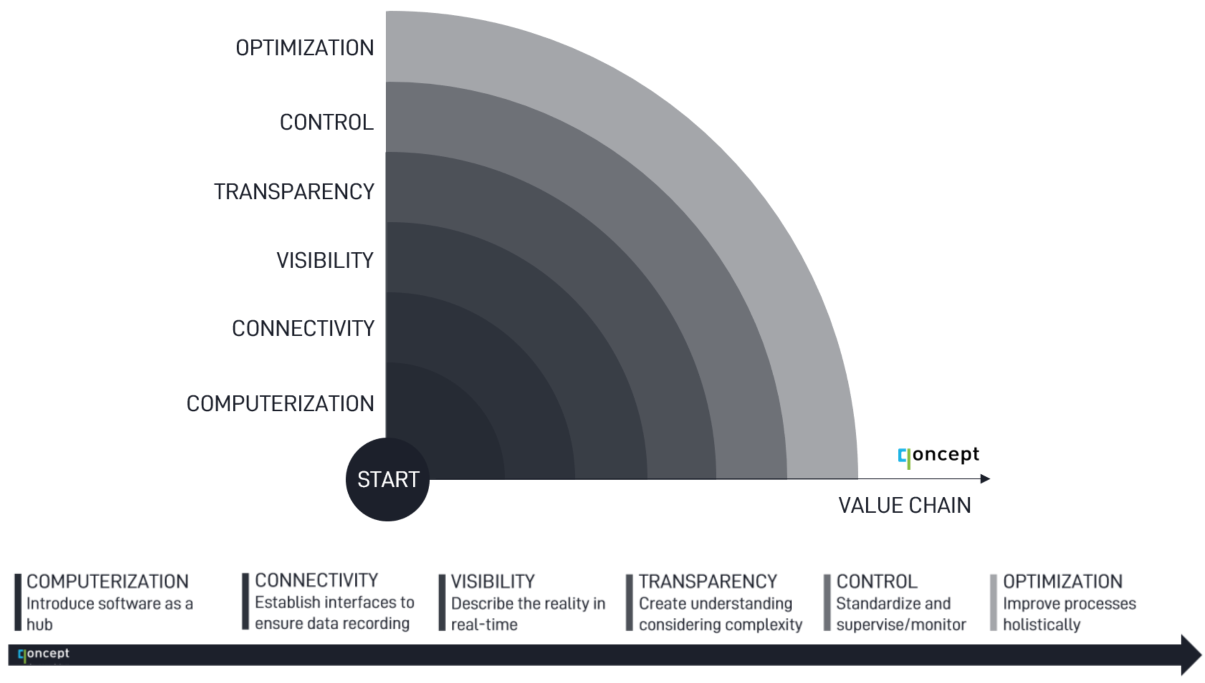


Figure 1: The systematization levels for state-of-the-art process control software systems.

4 THE REQUIREMENTS FOR AN INTELLIGENT PROCESS CONTROL SYSTEM

4.1. General Considerations Based on Systematization Levels

Although the above illustrated systematization levels must be considered holistically in the case of a holistic software system for the intelligent production (i.e. taking into account the entire value creation process), the basic systematization levels can also be used for each individual process. A more detailed illustrations of levels and tasks are shown in **Figure 2**. These individual levels (stages) or tasks that the software is supposed to fulfill range from data recording to optimization and are shown on the ordinate. The individual process steps are shown on the x-coordinate.

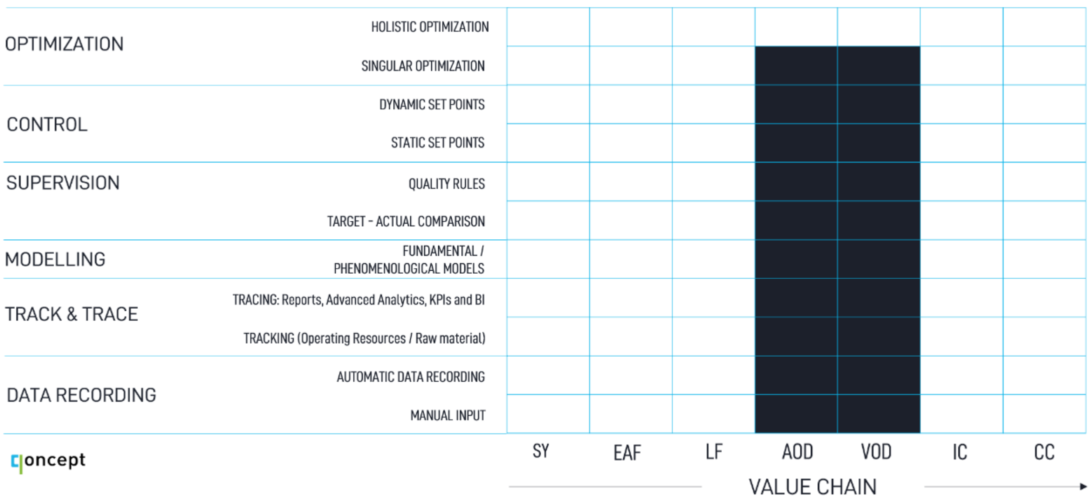


Figure 2: The two-dimensional approach of the development path for industrial software in the context of intelligent manufacturing.

Since this article only considers the AOD and VOD processes, the cross-process optimization is neglected for time being. In the following, we summarize possible questions that should be answered as part of a requirements analysis:

- Which process data are relevant for the respective process?
- Which sensors already exist, which sensors may have to be retrofitted and which can possibly be substituted by so-called digital sensors?
- Which data can be recorded automatically, which data must be entered manually?
- Which technical methods (e.g. interfaces to automation systems: OPC, OPC UA, etc.) are used to collect the data?
- How are the data and material flows so that complete tracking can be implemented?
- To what degree of detail (physical, chemical and mathematical) must the metallurgical process models be described?
- Can the complexity of the models be resolved and do they deliver solutions in real time?
- How are control values and rules for process supervision defined and evaluated in real time?
- How should and in what level of detail must treatment recipes (instructions) be implemented in the software (also in the context of UX)?
- Which dynamic set-point models can be implemented and how?

+ How is the optimization carried out and what optimization criteria are there (are these criteria mutually exclusive)?

4.2. More Detailed Considerations Taking Into Account the AOD and VOD Process

Figure 3 shows the most important building blocks of an holistic and advanced process control system. Such a state-of-the-art software systems needs a flexible and quickly adjustable interface, which receives and records process data in real time. Statically or dynamically calculated set-points must be sent to the equipment automation system (Level 1). Process-specific workstations in terms of graphical user interfaces (GUI) in the control rooms, and/or full-HD touch operating terminals outside the control rooms must enable interactions with the operator (user) in a user-friendly way.

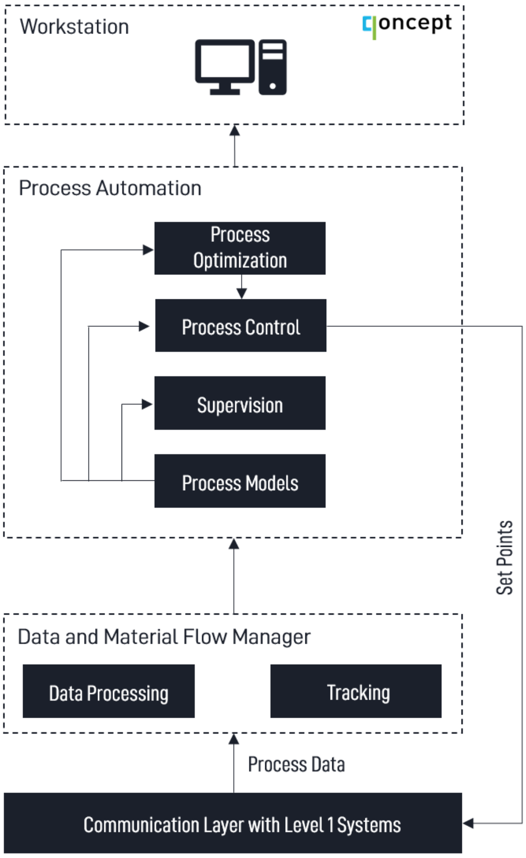


Figure 3: The interaction of the various modules for process modeling, supervision, control and optimization.

The software system must be able to perform the following tasks:

+ Tracking of heat orders, process data and events, material (scrap, alloys, slag former) and operating resources such as ladles and lances.
+ Process supervision of the metallurgical processes by comparison of target and actual figures and evaluation of quality rules.
+ Modeling of the different metallurgical processes (determination of the actual state of melt and slag).

- Control of the process using the set-points and treatment recipes (instructions) defined by the metallurgical engineer (static set-point control).
- Controlling and optimizing the processes by means of dedicated dynamic set-point and optimization models.

The metallurgical process models must be able to calculate the current state in terms of

- chemical composition of the steel bath and slag,
- weight of the steel bath and slag and
- temperature of the steel bath.

The initial conditions to be considered in the process model are the start temperature as well as weight and chemistry of the metal and slag. The target temperature and chemistry for tapping (for the AOD process) or the handover (in case of the VOD process) are further input parameters of the models. Additionally, the chemical composition and prices of alloy and flux materials are necessary for the material (alloying and slag additions) and reduction calculation.

In order to enable process supervision, the result of the process models must be displayed on the UI for the operator in real time. Provided that the model is carefully validated, the operator can actively take appropriate actions to the ongoing process based on the calculation results. Such actions could include stopping the oxygen supply when a certain amount of carbon is reached in order to avoid over blowing (VOD) or the gradual or continuous decrease in the amount of oxygen to zero (AOD).

The software system must include an alloy calculation model, which computes the required alloy additions to fit the target chemistry as well as temperature, i.e. for AOD tapping. The model must consider element yields for the steel bath and possible restrictions regarding alloying materials. The reduction calculation can either be incorporated within the alloy calculation or provided as a standalone application.

Next to static set-points, the system must provide fully automatic and semi-automatic set-point control models. The semi-automatic set-point control model must consider the initial conditions to calculate the blowing schedule (pattern) and (if necessary) additionally the material addition schedule. The latter requires a forecast calculation based on the static blowing schedule. The dynamic set-point control model must access the results of the metallurgical process model in order to apply corrections to the blowing and material addition schedules and for significant derivations of the actual process values from the set points.

The process optimization application must account for economic advantages and process related requirements. In doing so, different optimization criteria are possible:

(1) economic benefit by reducing the amount of reduction material (i.e. decreasing the oxidation of chromium),
(2) economic benefit based on a reduced treatment time and
(3) the need to adjust the handover or tapping temperature.

The latter can also be seen as an economical benefit, because not achieving the required temperature can lead to many problems for the entire steel making process. Thus, process optimization must be realized by coupling the desired strategy with the metallurgical process models.

5 SUMMARY

The classic automation pyramid divides the information technologies into individual levels, with each level having a specific task in production. The classic automation pyramid divides information technology into individual levels, with each level having a specific task in production. The 4-level approach is particularly widespread in the steel industry, which means that process control systems are referred to as Level 2 systems.

Regardless of whether it is strictly hierarchical (automation pyramid) or broken down to individual local and fully networked systems (Industry 4.0), the present article understands a process control system to mean a software system for supervision, control and optimization of metallurgical processes.

Considering the term computerization, it was pointed out that the current state of the IT landscape in the steel production industry can differ significantly from company to company. In order to support requirements engineering for a state-of-the art process control software system, systematization levels can support this process. Finally, a detailed description of the requirements for a holistic software system for monitoring, controlling and optimizing the metallurgical processes of AOD and VOD was given.

6 REFERENCES

[1] Tobias Meudt, Malte Pohl and Joachim Metternich: *Die Automatisierungspyramide - Ein Literaturüberblick*, Technische Universität Darmstadt, 2017.

[2] Jörgen Frohm, Veronica Lindström, Mats Peter Winroth and Johan Stahre: *Levels of automation in manufacturing*, ResearchGate, 2008.