RISK- & KNOWLEDGE MANAGEMENT WITH BLAST FURNACE PROCESS OPTIMIZATION SYSTEM*

Dieter Bettinger[1]
Harald Fritschek[2]
Thomas Kronberger[3]
Joachim Mauhart[4]
Martin Schaler[5]

Abstract

By introduction of expert systems individual judgement of process conditions and required actions receive support by rule based decision systems with an incorporated, standardized operation strategy. As the expert system contains the key operational strategy it mirrors central operational know how that can be adjusted and extended based on the gain of further insight, meeting the specific risk mitigation requirements and operational targets. Operation under guidance of the expert system leads to improved results regarding blast furnace (BF) performance, fuel rates and operational stability.

Keywords: Digitalization;Blast furnace; Process optimization; Process models; Expert system; Closed loop; Data mining.

[1] *Engineer, Process Optimization, Primetals Technologies, Linz, Upper Austria, Austria.*
[2] *Engineer, Ironmaking Specialist, Primetals Technologies, Linz, Upper Austria, Austria.*
[3] *Doctor, Engineer, Process Optimization, Primetals Technologies, Linz, Upper Austria, Austria.*
[4] *Process engineer, voestalpine Stahl GmbH, Linz, Upper Austria, Austria.*
[5] *Engineer, Process Optimization, Primetals Technologies, Linz, Upper Austria, Austria.*

1 INTRODUCTION

Process optimization systems are used to standardize the operation of metallurgical plants.
This paper is focused on how a process optimization system can mitigate the operational risk while pushing the cost reduction targets and at the same time serve as an important backbone for knowledge build-up and management.

2 BLAST FURNACE PROCESS OPTIMIZATION SYSTEM

2.1Generating information from data

The blast furnace provides process data from numerous sensors. Process models allow to extract relevant information or to condense the relevant essence from the huge heap of numbers.
The growing focus on the value of data can be summarized by the phrase "Data is the new oil. It's valuable, but if unrefined it cannot really be used. .." which the mathematician Clive Humby stated in 2006 [4]. In the context of this quote it is justified to reconsider the role of process models to digest data to information as an improved decision basis in complex data environments: Before listing two examples we would like to highlight, that the VAiron Blast Furnace optimization system is based on the hypothesis that "information without action is useless". In this context all model results and data analysis methods are bound to clear ideas of related actions.
The hearth wear model (see Figure 1, left part) provides precise information about the remaining wall thickness, wear rates, distinguishing between solid wall and scaffolds, identifying and elimination faulty measurements – while the proper interpretation of the pure raw data without this preparation is merely impossible.
Another good example for condensing information is shown in the Advanced Burden Distribution Model (Figure 1, right part): Data from the stock line, the distribution matrix, the charged materials and the chemical material analysis as well as the grain size analysis is combined to provide information about the layering structure and the radial distribution of the chemical and physical properties of the charged material within the furnace.

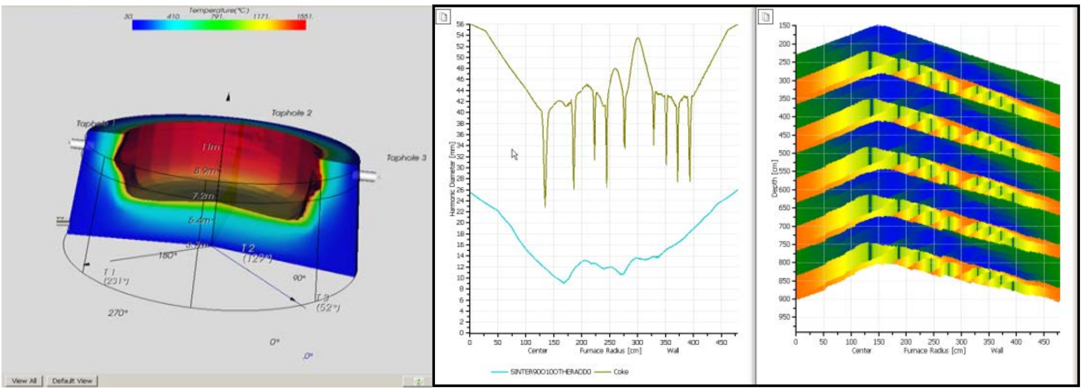

Figure 1. Data to information: 3D-Hearth Wear Model & Advanced Burden Distribution Model.

Ascending the knowledge pyramid

The knowledge pyramid related to process control is shown in **Erro! Fonte de referência não encontrada.**:

1. The blast furnace and its auxiliary aggregates are mapped through a multitude of measurements into a huge set of digital data.

2. These data contain information, which is either instantly obvious or can be revealed by models of the process optimization system.

3. The information provided from the process optimization system as well as information from other sources can be used by the blast furnace team to build up know-how. Unless organizational measures are implemented by the management the know-how tends to be bound to individuals. This individual know-how is stored in the brains of different operators, process engineers and specialists. Knowledge – management, the build-up and retention of know-how, is a permanent struggle in all companies, in particular in aging societies and in industrial branches that might seem not so appealing to potential applicants – which at least in some countries is a challenge for the steel industry. With every retirement know-how is lost – sometimes essential know-how. To cope with this problem, companies developed training programs, knowledge sharing methods and structured information such as work instructions, publications, tables, etc. that is filed beyond single experienced specialist in textual form.

4. The final motivation for this structured information is to provide a decision basis for actions – that is why we summarized them as action rules. An important example of filed information for daily operation is work instructions: in the work instructions – which are often printed documents – standardized action rules for well-defined situations are listed. This procedure targets on the establishment of a kind of "joint know-how" and standardized operation practice. While working instructions typically contain a huge amount of know-how that defines actions to be executed in case of a certain event and/or in a defined status, they usually still do not achieve a fully standardized operation:

- The individual rules required are not pre-selected according to the current situation - which can overburden the operators in particular in critical situations
- The rules leave certain room for individual interpretation and action open

5. We would like to draw the attention to the fact, that automation systems directly reflect process operation related knowledge: Due to its precise definition, a transparent control algorithm can be considered as a perfect knowledge management. While this might be obvious in the case of rules in a rule-based expert system, this also applies to control loops as well as to complex but well defined control actions and modelling calculations.

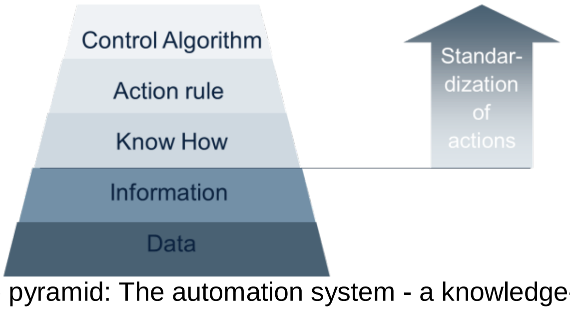

Figure 2. Knowledge pyramid: The automation system - a knowledge-management system.

Getting new information, knowledge and rules from data by data mining

In addition to the information that is provided to the operators from the HMIs related to the various models and from the reports the databases tend to bury huge amounts of data that – once stored – are not analyzed ever again. The potential patterns and correlations behind these data can be investigated with dedicated tools: VAiron offers possibilities to comfortably access and analyze these data for hidden correlations and impact factors with methods as they are used for big data analytics. This information can be used as the basis to develop new operational strategies and improve, extend (or simplify!) the set of control actions.

Digitalization of knowledge

The active mapping and digitalization of knowledge into an automation system (see Figure 3, upper part) is still a major challenge. During the implementation of a VAiron Expert System knowledge acquisition is one of the most important tasks. In this phase the individual know-how from the different operators and process engineers is collected and the joint operational approach is distilled. Although this process can be quite tedious it is rewarded by generation of an individual knowledge base reflecting the operational philosophy for the respective plant. It is quite common that different perceptions regarding the optimal control approach between the different experienced plant specialists appear and lead to usually very fruitful discussions which already represent a value of its own.

According to our experience it is an essential success factor, that the knowledge base is continuously maintained. The expert system should be used as a tool for knowledge management rather than considering it as a static collection of given rules.

The generation of new knowledge and rules from data was already covered in detail above. In addition to that there is the possibility to directly tune, modify and enhance the rule base by various machine learning algorithms. However it is rather delicate to incorporate such methods into the decision process of a control system, although adaptive methods have been successfully introduced into a large variety of different application: There always remains the risk that the system learned some “unwanted” behavior that might – out of a sudden –lead to critical control actions. Therefore we pursue a very cautious approach during incorporation of such methods into our optimization solutions.

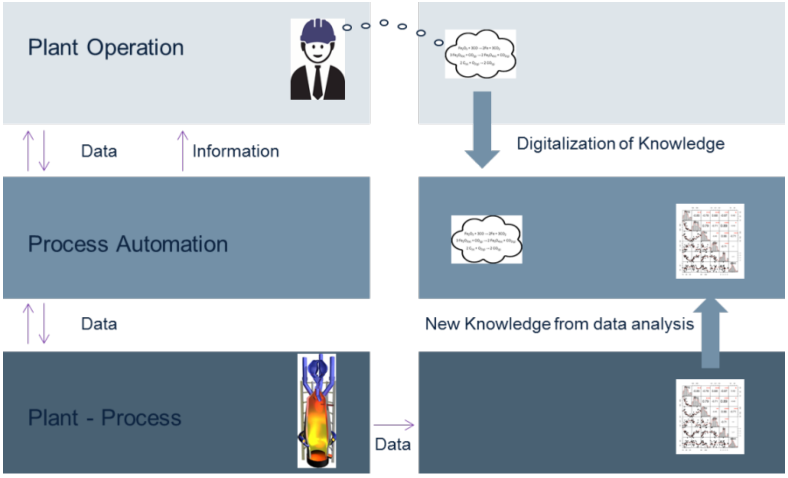

Figure 3. Data and Knowledge Flows in a modern automation system.

2.2 Knowhow Management with the VAiron Closed-Loop Expert System

The flexible knowledge base of the VAiron Expert System – a state-of-the-art rule-based decision making system [5] – is designed to play a key role in knowledge management: P*lant specific diagnosis, controls and corrective actions* – in addition to the *standard package* which have been developed in closed cooperation of Primetals and voestalpine Stahl Linz *are incorporated in the system:* During the implementation of the expert system the customer explains in detail the blast furnace operation philosophy followed by the definition of the set of diagnosis, controls and corrective actions to be used from the standard package and the new plant specific diagnosis, controls and corrective actions to be implemented. This *Knowhow Exchange Meeting* for a typical blast furnace project lasts for a few weeks. In this way the expert system plays a key role in the knowhow management process of the blast furnace:

- *Operation knowledge is clearly structured and defined in a computerized system*.
- *Learning by following the advices of the expert system*; e.g. new operation personnel has the possibility to efficiently learn the details of the process and understand the plant specific guidelines and practices.

The operator can accept or reject a suggestion any time within a predefined, configurable time period, after rejections he is forced by the user interface to enter a reason which can be used for an offline tuning of the Expert System – the basis for continuous improvement process.

Figure4. Improving the knowledge base using feedback from operators**.**

Thus the expert system guarantees a shift independent, consistent operation, which is advantageous in particular due to the long through process time and the even longer final response time (until transient effects are finished) of the blast furnace. By following the corrective actions of the fully tuned VAiron Expert System over 24x7 important improvements of the process stability and efficiency are achieved: Many examples of expert system installations worldwide show that a shift independent operation considerably increases the process stability.

Modifications and extensions of the expert system knowledge base

The expert system is a living system to maintain knowledge rather than a static source of knowledge. This implies the necessity for tools which allow changes in terms of modifications and extensions knowledge of the Expert System. The VAiron Expert System supports these tuning activities by process engineers in three different complexities:

- *Expert system parameters.*
- A graphical*Rule Editor User Interface*
- Implementation of new diagnosis and corrective actions with the *Metallurgical Model Builder*, an easy-to-use simulation scripting language.

2.3 Risk Management With The Expert System

Risks in blast furnace ironmaking

Managing risks of the blast furnace process is an ongoing task that includes assessment and mitigation strategy for those risks. Risk assessment includes both the identification of potential risks and evaluation of the related potential impact. A risk mitigation plan is designed to eliminate or minimize the impact of the risk events—occurrences that have a negative impact on the process. Main risks for causing major disturbances in blast furnace ironmaking are among others:

- Incorrect burden control
- Improper selection of the burden distribution
- Problems during furnace shutdown and startup
- Losing control of the input-output balance deviations

The mitigation of these risks and the avoidance of the consequences is a complicated process, i.e. it involves many steps that have to be executed in the right order at the right time, it needs various input data from different sources over different time interval and it requires advanced heat and mass balance model calculations. Therefore an expert system in closed loop mode is the tool of choice for managing the risks of modern blast furnace practice.

Table 1. Three types of risk mitigation methods provided by a mature optimization system

Precise information and prediction of critical operational situations leading to better understanding/transparency of the process, more focused awareness	Example: Expert System Diagnoses, Data Validation; Hearth Wear Model, Shaft Simulation, Burden Distribution

of deviations of process conditions and more time to react due to earlier indication of critical situation	Model,…
Precise control of critical process parameters leading to standardized operation with defined risk levels	Example: Hot stove energy load, XPS-thermal control (tapping temperature & Si content)
Automation of complex work procedures (in particular if they can cause critical process situations) excluding potential sources of human error by automated sequences	Example: Digital assistants e.g. Furnace Shutdown and Startup Support Package

Burden control

The purpose of the burden control model is to establish a burden composition achieving target values for coke and injectant rates, slag basicity, hot metal quality and burden specific rates. The interaction of the burden control model with the process engineers and operators as well as the closed-loop expert system is the backbone of standardized plant operation.

Selection of the burden distribution

The closed loop burden distribution control is a unique package of the Primetals VAiron Expert System for process stabilization and reduction of the fuel rate designed to reduce the risk of using unfavorable burden distributions for blast furnaces.

Data Validation

In addition to classical limit or trend based validation, balance based data checks are performed. In case the same measured values (e.g. raw material data, blast and injectant data, product and by product data as well as process data) are repeatedly identified as the most probable measurement faults from balances. the system alarms the maintenance engineer to schedule proper checks.

Assistance during furnace shutdown and startup

The *Furnace Shutdown and Startup Support Package* is fully integrated into the expert system and designed to minimize the risk of shutting down the furnace with incorrect operational procedures, additionally it guides the operator in starting up the furnace by selecting the correct measures for safely increasing the production rate at the appropriate pace.
Depending on the planned duration of a furnace shutdown usually a different set of actions is performed before and after the shutdown. With the *Furnace Shutdown and Startup Support Package* the blast furnace engineer can define different patterns for different shutdown durations.

Observation of input-output balance deviations

In order to detect the risk of a considerable accumulation of certain elements at an early stage element balances have to be closely observed. The Expert System cyclically checks short and medium term mass balances and visualizes the respective diagnoses similar to traffic lights with normal (green) areas, warning (yellow) ranges and alert (red) zones on the y axis (Figure5).

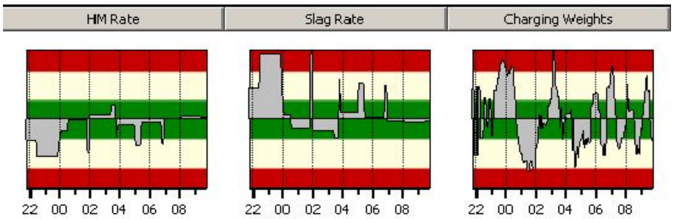

Figure5. Visualization of selected expert system diagnoses as traffic lights.

2.4 Benefits

The benefits from the process optimization system can be basically assigned to three aspects:

1. The joint definition of action rules in the knowledge base of the expert system leads to shift independent operation. This assures a standardized operational practice throughout all shifts. A standardized operation does not automatically imply an optimal operation, but an operation that is not standardized definitely cannot be optimized.
2. A better *analysis of the information hidden in the process data* leads to improved understanding of the *current process conditions* as well as a *clear determination of the impact of actions*. Due to well defined *risk level management* it is possible to go closer to the edge in the *optimization of the process*.
3. The joint knowledge base serves as a precise tool dedicated to collect, adapt and extend operational knowledge in action rules.

The main difference between manual operation and operation with the expert system is that the latter is characterized by more frequent, but smaller control actions. The resulting smooth operation avoiding heavy control actions and critical process situations leads to:

- Extended availability of blast furnace equipment,
- Longer lifetime of the equipment,
- Reduced maintenance efforts and costs

Performance results achieved with the Closed-Loop Expert System

In addition to the long term benefits mentioned above the VAiron Blast Furnace Expert System gives also immediate benefits where the system pays back the investment costs starting on the first day of operation:

- Reduced specific fuel consumption and therefore reduction of emissions.
- Increased productivity of the blast furnace.
- Stable hot metal quality even if cheaper, low graded raw materials are used.

Operators tend to run a furnace with a higher hot metal temperature than targeted, giving them more safety in case of problems. By doing that, valuable coke and/or auxiliary fuel is wasted. Closed loop expert system operation allows to run the furnace at a defined risk level closer to its limits, therefore saving fuel but still maintaining high operational safety.

The typical reduction of fuel consumption is between 5 and 15 kg coke equivalent per ton hot metal. The savings achieved by the VAiron Expert System in previous projects with respect to different blast furnace sizes and coke equivalent rates have already been analyzed in detail [6].

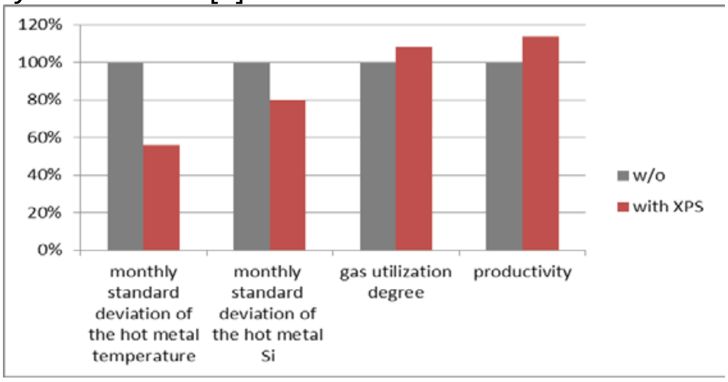

Figure 6. Monthly KPIs and the impact of standardized operation with VAiron Expert System.

In Figure 6. the positive impact of standardized operation on monthly key process indicators is shown. The Expert System reduces the standard deviation of the hot metal temperature and the hot metal Si while increasing the gas utilization and the blast furnace productivity, figures were derived from the same projects as in the previous chapter.

3 CONCLUSION

A few of the manifold of aspects of digitalization have been picked, with the focus on the generation of information and finally know-how from data: The digitalization and mapping of know-how into the process optimization system has been illustrated including new methods to edit and maintain action rules. These standardized set of rules lead to unified actions in blast furnace control and finally smoother process operation.
It was illustrated how the process optimization systems contribute to meet the growing cost pressure by continuous improvement of know-how regarding operational practice and by keeping defined risk margins.
Based on recent developments we expect, that the progress in instrumentation, data analytics, machine learning and simulation will trigger further improvements in the field of process optimization systems for the complex blast furnace process.

REFERENCES

1 Michael Haupt. Data is the New Oil. Trans [internet]; 2016 [cited 2016 May]. Available from:https://medium.com/project-2030/data-is-the-new-oil-a-ludicrous-proposition-1d91bba4f294.

2 T. Kronberger, M. Schaler, B. Schürz, K. Stohl. Expert Systems Controlling the Ironmaking Process in Closed Loop Operation in Expert Systems.InTech, ISBN 978-953-307-032-2. 2010.

3 O. Lingiardi, G. Cegna, G. Tomassini, C. Quispe, E. Frank, M. Schaler, B. Schürz. High Efficiency Blast Furnace Operation with the Process Optimization System. AISTech 2014 proceedings. 2014; Volume I.

4 Maarten Geerdes, RénardChaigneau, Ivan Kurunov, Oscar Lingiardi, John Ricketts. Modern Blast Furnace Ironmaking – an introduction. Third Edition. 2015.

5 Martin Schaler. VAiron Blast Furnace Process Optimization– 25 Years of Experience with Closed-Loop Expert Systems. AISTech 2016 proceedings. 2016.

6 Martin Schaler, *VAiron Blast Furnace Process Optimization– 25 Years of Experience with Closed-Loop Expert Systems*, AISTech proceedings, 2016