# MANAGEMENT OF QUALITY CONTROL AT PRODUCTION OF CONTINUOUSLY CAST SLABS

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**Abstract**
*The paper deals with the optimization and control of production flow in a steel plant, namely with continuous casting of slabs. Data collection, processing and well-arranged access to the management of continuous casting of steel using the original software is essential for successful management of control during casting of slabs with regard to quality of final products. The article gives an overview of the standard features of an information system in steelworks, it specifically deals with the integration of the developed the original software into the information system of steelworks, which monitors casting parameters linked to the quality of slabs and plates. The resulting data usage and experience of engineers are used for formulation of prediction rules for an on-line alert signalling the possibility of formation of defects. On the basis of these rules the guidelines are then developed guidelines for the recommended procedure for handling of slabs. In conclusion, the authors evaluate the benefits of this procedure in the steel plant Eras Vitkovice Steel Ostrava.*

**Key words:** *Management, continuous casting machine (CCM), software, prediction, slab*

## 1. INTRODUCTION – OBJECTIVE OF RESEARCH

The aim of the paper is to present an analysis of the effects of casting parameters on the quality of continuously cast steel slabs, and to find connections between the casting parameters and the resulting quality or defects of slabs, and of the products rolled from them. This approach is a necessary prerequisite for prediction of defects, which provides the steel plant management a tool for operative production management and quality optimization.

In order to achieve these objectives it was necessary to create a dedicated software, which efficiently stores the data from the continuous casting process and at the same time provides a tool for their further use at industrial operation and in research. Complete data from the production process were thus concentrated in one place – on the server. The data had to be structured and stored with use of sophisticated algorithm into the so called data warehouse, so that they could be assigned to the produced slabs and to the parameters of sheets rolled from them for study of their influence on the final quality.

The design and realization of the software made it possible to achieve also an auxiliary goal – an original effective long-term monitoring and analytical tool was created for tracking of sequences of heats at machines for continuous casting of steel. Technologists at the steel plant can thus make a analysis of the causes of defects of the slabs and of the sheets rolled from them. Management of the steel plant can on the basis of the detailed statistical analyzes increase production efficiency.

At solution of the above scientific and technical problem we used the experience acquired at processing of the data acquired from the steel plant U.S. Steel Košice, as well as from special measurements performed in the Třinec steelworks, a.s. The works were realised within our participation in the projects solved in cooperation with VÚHŽ Dobrá, VŠB TU Ostrava, VUT Brno and with the above mentioned metallurgical plants.

On the basis of the analysis and statistical analyses we selected key indicators, both for the evaluation of thermal processes and for evaluation of defects of slabs. We have defined thermal processes running on CCM, identified critical technological process parameters, which affected them and had a

decisive influence on the quality of the slabs. The research results then led to the specific proposal of algorithms for prediction of defects.

Analysis of this issue cannot be exhaustive, because continuous casting technology is constantly developing, it uses the latest scientific knowledge of an interdisciplinary nature, and optimization with the output for prediction of defects requires long-term involvement of bigger scientific and research team, which must collaborate with the technical staff of the steel plant.

## 2. SYSTEM ARCHITECTURE

Analytic software tool LITIOS is a super-structure over the running sub-systems of the automated control system (hereinafter ACS) in EVRAZ VÍTKOVICE STEEL, a.s.

Acquisition, aggregation and storage of data in the application database are performed by the services of „Import“ and „Re-count“. These services run continuously on the server and their function consists in data updating at the moment of their entering into the sub-systems of technology. In this way the most rapid availability of all functions of the software is ensured. All the data are stored in the data warehouse, in which they are accessible with use of the client application of the type client - server from the users' computers. **Fig. 1** presents a conceptual diagram.

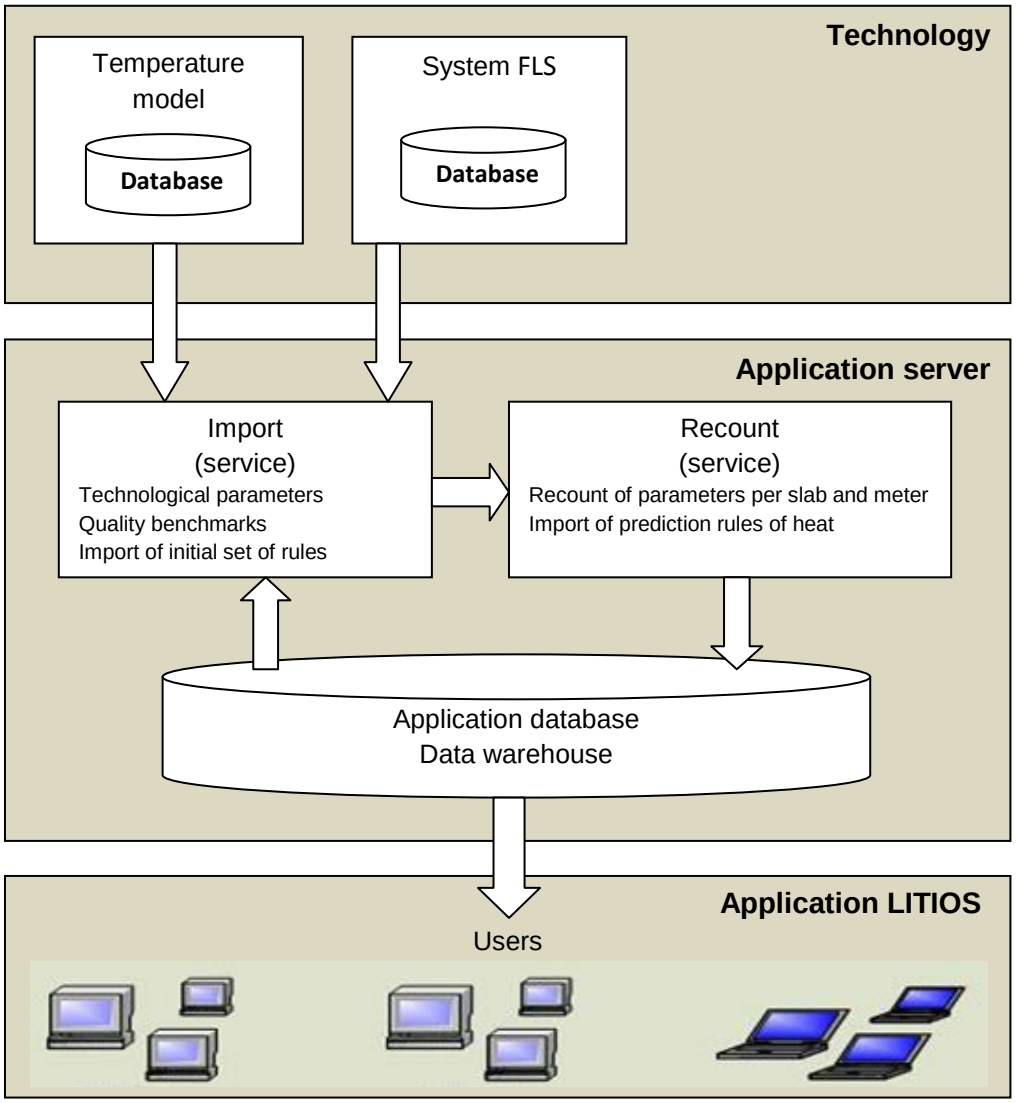



*Fig. 1. Diagram of creation of the data base for the analytical tool LITIOS*

The data stored in the data warehouse can be retroactively searched and displayed and it is thus possible to analyse any realised heat [2].

## 3. ALGORITHM OF DATA ASSIGNMENT PER METER OF SLAB ACCORDING TO THE FIELD OF ACTIVITY

It was necessary to resolve how to store the data, how to aggregate them and assign to the slabs with an accuracy of one meter, and moreover how to file interpret the effect of individual measured parameters from the mould till cutting of the slab on the flame cutter.

Solution of these tasks resulted in optimisation of data storage. Data aggregation has been proposed in a sophisticated manner in such a way that all the data are made available upon the request of the user, and particularly of the steel shop technologist. The data from the temperature model, saved every ten seconds, can be displayed in detail as they were created, and then in relation with the so called field of activity of the given measured value. The field of activity is a length interval of the strand, where the given quantity influences the course of casting, i.e. where the quantity performs its effect. The monitored field of activity may be different for monitored parameters. It is especially important for casting rate, when technologists need to know, what was the speed of slab in the mould, in the zone of secondary cooling or even under the selected cooling nozzle (field of activity at single place).

The data are aggregated by the lengths of one meter and statistic characteristics are saved for each section of the field of activity. For statistical purposes related to evaluation of slab quality it is then possible to assign the data to individual slabs and then to the final products rolled from these slabs.

The data stored in this manner make it possible to simulate in future the course of the slab through the casting curve and to display graphically the selected data. Another possibility of use of the program consists in analysing the data by mathematical and statistical methods. These analyses then serve as a basis for more precise specification of data in the table of causes of defects (**Fig. 2**). Classification of defects is performed directly at the rolling mill by commissional analysis in accordance with the catalogue of defects [4].

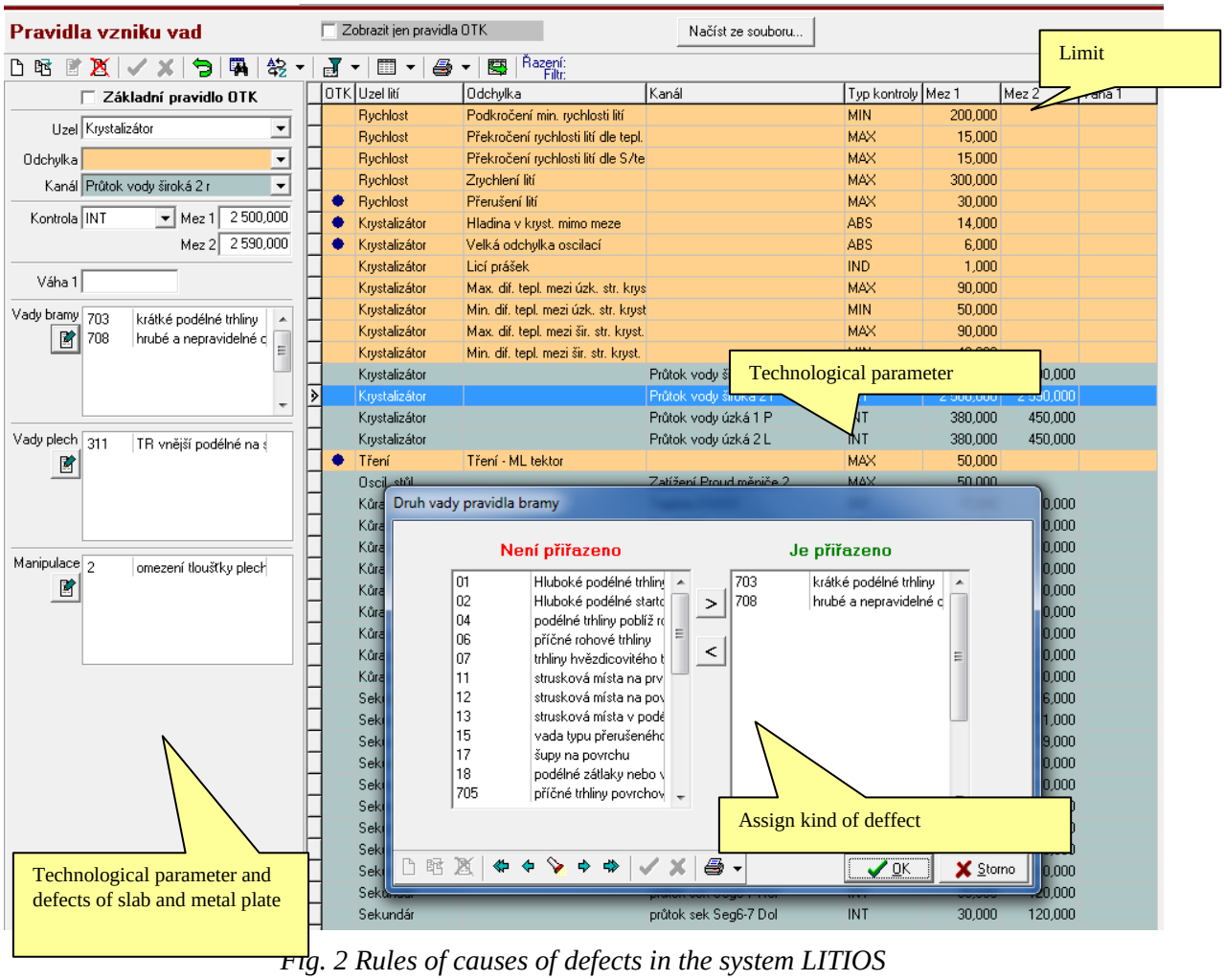



*Fig. 2 Rules of causes of defects in the system LITIOS*

The data stored in the data warehouse can be retroactively searched and displayed and it is thus possible to analyse any realised heat [2].

## 4. GRAPHIC SIMULATION

During operation of the current system LITIOS very long responses of users accessing the data – typically trends of values (**Fig 3**) of individual measured channels for long period – were registered. For this reason a solution was proposed, which divides the current uniform database into two parts. The first database contains only technological data sent from the temperature model system, the second part contains only aggregated data necessary for the user.

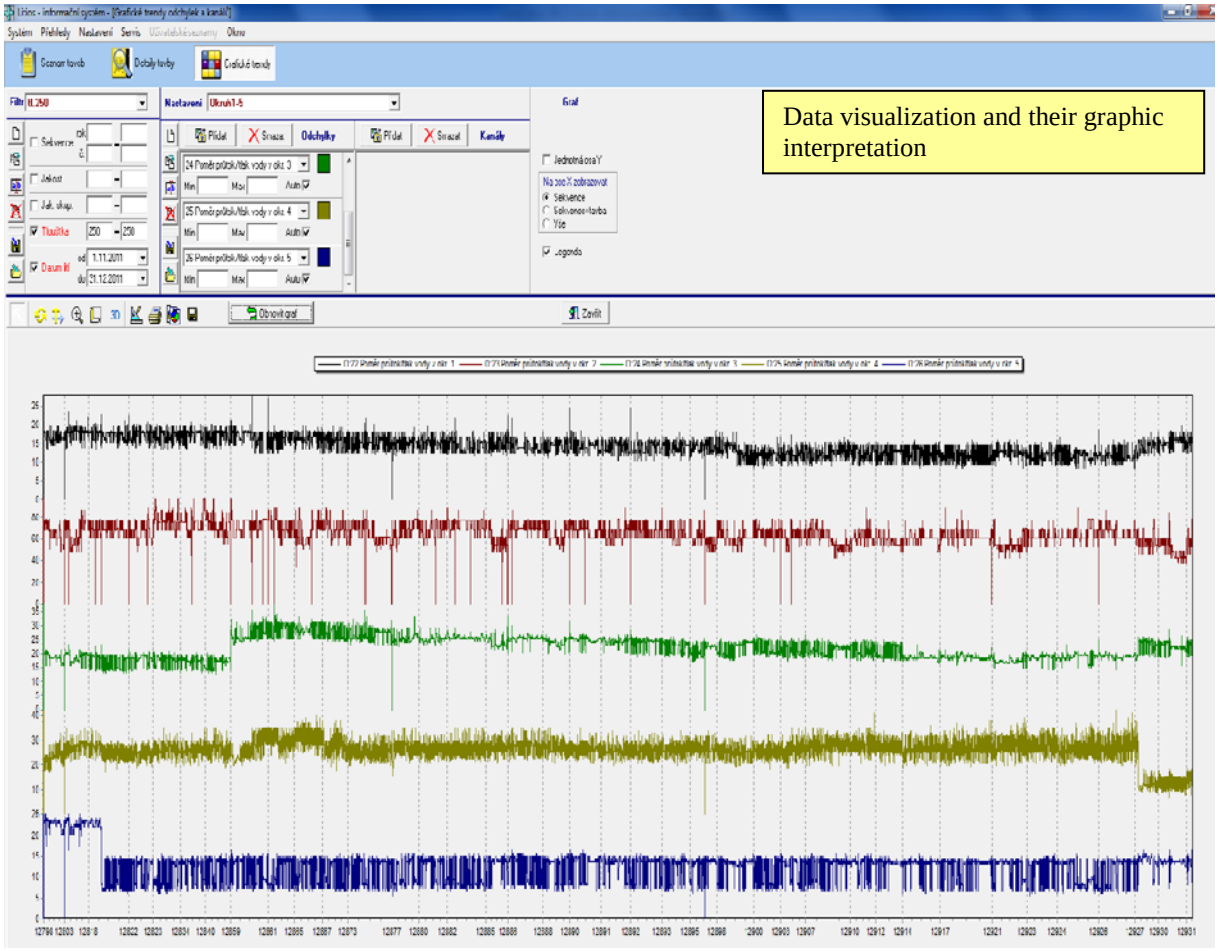



*Fig. 3 Screen presenting information on heats in the program LITIOS*

The measured values of technological data are sent every 10 seconds to the database of real-time data, from which they are taken by the service realising aggregation recounts and stored in the database of user data. Both databases contain data always for a period of one year. That's why another database exists, which contains time intervals of data in individual cycles of year and moreover also current setting of channels (technological parameters), which need not be stored in annual data.

Program LITIOS forms also a final table of prediction rules. Moreover some functions were programmed in this program for immediate and retroactive analysis of processes of casting, melting or sequence. It is namely visualisation of selected technological parameters in determined sections and intervals at travel of slab through the continuous casting machine. The application was thus extended by another possibility of viewing the data obtained during the process of slab casting.

This concerns the module „Course of casting", with use of which it is possible to visualise in great detail values of selected quantities in relation to the current position during movement of sequence, heat or directly individual slabs in the casting channel. The application uses data of approx. 400 channels, used for calculation of temperature model. Values of these channels are measured at a constant period of 10 seconds. These data are with use of data services of the program LITIOS processed on the application server and data from these channels are here connected with the information from the main database FLS.

Values of channels are thus assigned to heats and individual slabs.

Overview of function of graphic simulation:

- graphical visualisation of movement of sequence-heat-slab in the casting channel in relation to the whole casting route or only to the selected segment of the route,
- visualisation of the values of selected channels for the whole course of sequence-heat-slab,
- it is possible to regulate the movement in slow or quick steps,
- current values of selected channels are assigned to each time moment during movement, that's why it is possible to find possible cause of the problem within sequence-heat or slab,
- graphic visualisation of resolution.

This graphic simulation serves to technologists and researchers and helps them setting of to set the limits of prediction rules and their subsequent correction.

## 5. SYSTEMS FOR PREDICTION OF THE SLAB QUALITY

At present, it can be said that the basic technical development of classical equipment for continuous casting of steel has reached such a level that further development is often not necessary. Entire group of continuous casting processes, usually characterised as continuous casting of billets with dimensions close to the finished products (NNSCC - Near Net Shape Continuous Casting), are nowadays not considered as "classic" continuous casting machines (CCM).

Development and technical improvements of individual conventional CC technology nodes continued in the areas of ceramics, protective slag and casting powders, as well as of protection of the pouring stream from the ladle and tundish, of material (CuCrZr), shape, and cooling oscillation of the mould, automatic addition of casting powder into the mould, molten steel level control in the mould, secondary cooling (two component system), electromagnetic stirring in the mould and in the secondary zone, guiding and traction elements, systems of bending and straightening of the strand, strict holding of the casting axis, to fully automation of the entire process of casting at the CCM with exclusion of human factor. In addition, a number of measurement and diagnostic instruments was developed for improving the quality of casting and maintenance of the CCM, indication of slag and breakouts, etc.

Various, more or less minor metallurgical, technical and technological improvements, are naturally continuously realised in these areas, but in general it can be said that other possibilities for ;increasing the efficiency of production through major changes are already constrained by very narrow barriers.

One of the areas, where some reserves still exist, consists in an increase of the quality of the continuously cast blank and its control (hereinafter CCB), and in particular of the final products of metallurgical plant. This can be achieved by implementation of prediction systems, in the first stage of prediction of quality of CCB and consequently of the final products. According to the designation of these systems their primary objective is to predict the quality of the products at the time they leave the production line or even before it.

A possibility exists here of transition from discontinuous production in the sector ´liquid steel - rolled product´ to continuous production, with evidenced savings in the energy intensive heating before the subsequent forming of the CCB. Prediction of quality allows direct processing of the CCB without significant risk that lack of their control in the cold state with subsequent elimination of the detected defects will cause occurrence of rejects or that final products will have defects degrading their quality. Even in the case of occurrence of irreparable defects on the CCB their elimination before the unnecessary further processing is economically advantageous.

The second, perhaps still not sufficiently reckoned asset of prediction systems consists in the use of a feedback between the quality of the CCB and that of the final product and technological parameters of casting at the CCM, or parameters of CCB processing on the rolling mill. Archiving and statistical processing of huge number of cases of this relation (parameter versus quality level) can enable with an even surprising success finding of the optimum technological parameters for casting and for further processing.

The issue of success of prediction is naturally not yet quite clear. For example, if the company VoestAlpine AG declares that success of its CAQC system in both directions exceeds highly ninety percent, this can be considered as a great success. Numerous publications exist about this prediction system, for example, [4], [5], [6], [8].

The word "prediction" is, as well as the word "quality", taken from Latin. Systems for prediction of quality of metallurgical products are nowadays already quite well known. In investigated field we are talking about prediction of the CCM quality, and about the predicted quality of the final metallurgical products based on this primary prediction. These systems are applied particularly on the slab CCMs, where charging of hot slabs without their predicted quality is no longer common. Currently the renowned manufacturers of the CCM already offer the CCB quality prediction systems as part of the supplied CCM. Our existing experience from Czech steelworks show, however, that these systems are not functioning, it means that resulting predicted codes of according to the provided algorithms and specified limits are far from corresponding to the real state of the CCB quality.

This, however, requires more detailed explanation. The software of those systems is faultless, that is algorithms for assignment of the instantaneous value of the given parameter to the length section of the CCB, calculation of the degree of quality for the entire divided CCB from these partial length sections of the CCB and determination of the level of quality on the basis of quantitative measure of deviation from the preset limits. These limits, however, must be in most cases determined by the CCM operators. Both the manufacturers and suppliers of the CCMs state that commissioning of this system must be performed for each CCM individually, on the basis of non-communicable experience, preferably from several years of operation.

This "commissioning" of the system of prediction consists in determination of reliable limits of technological parameters, exceeding of which causes defect, and in selection of defects resulting from violation of the given technological parameter. Commissioning of the prediction system is usually very laborious, time-consuming matter and, if implemented by the foreign supplier, it is also very expensive for us. Offers in this area from reputable companies (VoestAlpine AG, CONCAST AG) are in the range from 1 to 2 million USD.

Prediction systems differ individually by their technical execution, degree of perfection, form of outputs, degree of actual usability, etc. By technical execution we mean, for example, the number and type of monitored technological parameters, the number and type of predicted defects, the number of degrees of quality, dispositions for continuously cast blank according to their technological flow in the steel plant, etc. The basic principles and philosophy of the system are, however, similar and they can be generally formulated as follows: Quality of each CCB is determined on the basis of the knowledge of technological parameters of casting. According to this quality, usually given in the code or degree, a disposition for the method of further processing of the CCB is then issued.

Thus formulated definition of the prediction system is valid for prediction of CCB quality. If the system is developed also for final products, its general principle is analogous to the prediction system for CCB. It means that quality of the final metallurgical product is predicted on the basis of knowledge of the technology of further processing of the CCB. Connection of both prediction systems therefore makes it possible to predict the quality of the final product on the basis of the entire process flow of steelmaking from the liquid phase till the final rolling. In addition, the prediction system allows optimisation of the used technology and taking of measures during production aimed at reduction of defectiveness of the intermediate product and thus also of final product. Economic benefits of the prediction system are much greater than the money spent on its operation.

The above characteristics of the systems for quality prediction is general. It goes without saying that achievement of the said objectives and full functionality of the system requires number of partial, progressive, time-consuming and technically challenging steps. They are more or less evident in some examples of the cases presented in the literature.

Prediction systems are developed and implemented primarily for the plants operating slab CCMs and producing flat products. The rationale for this is relatively easy, if we look for the cause not in the system itself, but in the purport of its use. It is first and foremost the requirement for hot charging of slabs, which is not common requirement for square billets. In the case of slabs and sheets and strips rolled from them, their surface quality plays the primary role. Without the prediction system the risk of a large share of defective finished products would be significant, or in the case of a cold route, requiring inspection of each slab, economic losses are obvious.

Furthermore, in slab CCMs the number of CCBs is smaller by an order than the number of continuously cast billets. Therefore for example at the manufacture of heavy plates an identification of defective place on the slab, which was the cause of the defect on the sheet, is also easy. This is difficult at production of long products from billets. In this case it is easier to assess the whole heat or its parts, or the quality of the whole "batch" of long product made from one piece of billet.

What concerns the system as such, as it was said, there is no problem, which is supported also from the emphasized statement of the authors of CAQC and others, that the system is equally applicable to slabs, blooms and billets.

The theory and practice dealing with defects and their prediction is described in numerous publications, for example [12], [13], [14], [15].

## 6. PROPOSAL OF PREDICTION OF DEFFECTS AT THE COMPANY EVRAZ VÍTKOVICE STEEL

Basic philosophy of systems for prediction of CCB quality seems to be quite clear from the pieces of knowledge mentioned in the literature [1], [2], [3], [7], [8]. Predicted quality of slabs is based on the knowledge of casting conditions and their influence on the formation of defects. This prediction is then used for determination of dispositions for the further processing of the CCB.

However, in practical operation of specific CCM, realisation of the quality prediction and achievement of useful results presents highly complicated problem. Each CCM has its own specific characteristics of technical facilities, assortment of cast steel, quality of the information system and, last but not least, creativity of the steelworks management. In the original proposal of the prediction system in the company Eras Vitkovice Steel, a.s., in addition to theoretical methods, also many years of author's experience with collaboration with continuous casting technologists and other personnel engaged in research in this area were put to good use.

**Methodology for proposal of the prediction system**

Thus simply defined system, however, consists of several partial activities (nodes), the development and mutual interconnection of which is extremely technically demanding and time-consuming.

Taken literally, the "prediction system" itself consists of activities from the INPUT of steel into the casting machine till the OUTPUT of the CCB from the flame cutting unit. It is, however, obvious that development, implementation or operations of prediction systems are not possible without a basic database and other complementary activities.

Partial activities (nodes) for prediction of defects are described below methodology for prediction of defects is then clearly shown in Figure 48.

INPUT. These are technological parameters for processing steel in the ladle furnace and its casting at the CCM (sometimes called "variables"), chemical composition of the steel, "events", type of casting without tubes, etc., operational conditions of the type ´condition of the mould´, etc. Generally

speaking these are all process parameters (measurable or manually entered), which can in any way affect the quality of the CCB. They are measured or entered into the control computer (CCM); their number may be very different.

SEGMENT. Here, the process parameters are processed to the time or the length section of the CCB in such a way that the maximum or minimum value for this segment is recorded. Segment length is usually 0.5 or 1.0 m, or time step is 5, 10 or 20 seconds. It can be also directly the CCB length, if shorter segments make no sense – CCB is no more cut to smaller lengths, the parameters do not apply to the sample, etc.

Continuously cast blank - CCB. Technological parameters are aggregated to 1 m of the cast length and they are assigned to the CCB. The maximum, minimum value, average and standard deviation are calculated per length of one meter. The events of the type Y = Yes or N = No are also assigned to one meter of the cast length (for example type of casting powder). These calculated values assigned to the CCB are then used to calculate the resulting prediction code and they serve also as an input for detection of dependencies "parameter – CCB quality".

DEGREE OF QUALITY. In this node the resulting quality prediction of the CCB is calculated from the values from the preceding node with use of prediction rules. The quality is given in degrees. The simplest evaluation is 1 (occurrence of defect) and 0 (no occurrence of defect), but it is also possible to use more detailed evaluation. In the case of Baumann sulphur prints the scale from 0 to 5 is used, where zero represents no occurrence of defect and marks from 1 to 5 evaluate the degree of defect according to the standard operating procedure (SOP).

OUTPUT. Next handling of the CCB is determined in dependence on the degree of quality. It is usually in code A - N, i.e. direct hot charging into the equalising furnace of the rolling mill (A), or cooling of the slab, its inspection and elimination of defects (N). Some other dispositions may be given, such as direct route, inspection or reassignment of quality.

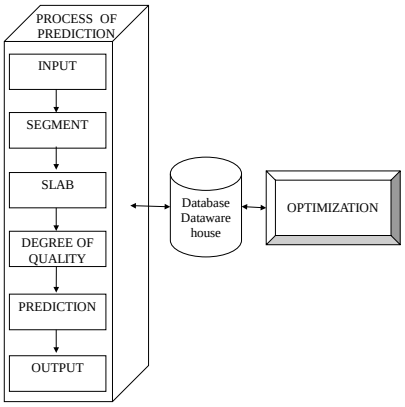



*Fig. 5. Methodology for prediction of defects*

DATABASE. The database stores all the data needed for the work of the prediction system. It performs moreover connection of files for search of dependencies "parameter - defect", testing of input data and files, and archiving of data from the CCB (SEGMENT) DEGREE OF QUALITY, data on the CCB quality, chemical composition of steel for the heat, identification of the CCB, etc.

INPUTS INTO DATABASE. All the necessary inputs on the quality of the CCM, on macro-etches or on Baumann sulphur prints of the samples, identification data of the CCM, and so on are entered into the database.

DETERMINATION OF DEPENDENCE. Combination of the files on the casting parameters and the CCB quality makes it possible to create basic important activities for determination of the degree of

CCB quality, and mainly for determination of credible limits of individual parameters, the exceeding of which causes defects. These activity comprise mainly statistical analyses of large files.

OPTIMISATION OF CASTING TECHNOLOGY. This output is not directly related to the quality prediction, but it is an important tool for determination and modification (optimisation) of technological parameters of casting. Optimal technology and its maintaining is a prerequisite for perfect CCB quality.

The prediction system described above is general. Based on the available literature and the experience gained, it can be stated that majority of today's operated systems works in this way. Due to the large number of different parameters, outputs and activities it is logical that each system for the given CCM is unique and that it differs from others in some or even in many "details". In principle, however, it is possible to develop and implement a prediction for the already operated CCM in the particular steel plant on the basis of the above scheme.

## 7. REALISATION OF QUALITY PREDICTION IN THE LITIOS SYSTEM

Experience and knowledge described in the previous chapters, led to the design and practical implementation of the prediction system in the company Eras Vitkovice Steel, a.s.

Statistical analysis of the movement of the values of selected variables and search of mutual relationships between the parameters (variations) and slab defects were the necessary prerequisite for the proposal of system for of slab defects. With help of these statistical and analytical analyses we created tables of determined limits for the values of casting parameters, for individual groups of steel grades and for slab thicknesses. A table was proposed with limits for prediction of defects with the causes of the given quality prediction and other next handling of the slab.

At the start of solution we created files connecting identification codes of the sequences, heats, steel grades, groups of steel grades, slab dimensions, primary and secondary cooling of slab with selected individual deviations of technological data from the data set according to technological SOP. The data are taken from the superior FLS system, supplied by Mannesmann, and also from the thermal model, see Figure 1

Using statistical methods and knowledge experience of technologists we created tables of limit values (prediction rules) for individual groups of steel grades and slab thicknesses. When selecting the limit values we took into account different impact of various individual casting parameters on potential formation of defects in the slabs in dependence on their thickness (and also on their length and location of the liquid core in respect to the plane of straightening of the slab), chemical composition of steel in groups of steel grades, etc.

Knowledge of the frequency of occurrence of defects in slabs and in finished rolled sheets in connection with the casting parameters were used for proposal of a table of causes of the defects in slabs and in sheets. These rules were programmed and further adjusted according to the requirements of quality control, department. After verification in normal operating mode these prediction rules will be further continuously improved and modified.

The original software tool for prediction of defects is in the system designed in such a manner that limits are set for each parameter and when these limits are exceeded, it indicates the possibility of formation of defect in the slab and consequently in the sheet. Methods of statistical analyses were used for setting of those limits. Basic descriptive statistics and frequency was conducted for each variable histogram of its frequency was plotted. Furthermore, methods of correlation and regression analysis were used. We also put to good use the results of method logistic regression and neural networks.

Prediction rules were set for each combination of the group of steel grades and slab thickness. In this way $x$ times $y$ prediction tables were created for $x$ groups of steel grades and $y$ slab thicknesses. The proposed solution is, however, universal for any number of tables in the case that number of group of steel grades or of slab thicknesses would increase. At solution of these issues the program was complemented by the possibility of defining multiple different sets of rules for each combination of

the group of steel grades and slab thickness. This makes it possible to try different settings of rules for the given type of slab and to refine the prediction rules on this basis. Exactly one set of rules defined by the technologist is assigned to the given cast heat. Due to the fact that prediction table contains often large number of technological quantities, the technologist has a possibility to choose and mark the most important ones, which will be visualised and serve as a basic overview of the slab quality for the workers of the quality control department. The program is designed in such a way that various sets of prediction rules can exist (for technologist, worker of the quality control department, researcher) and it is thus possible to simulate their success.

After selection of the appropriate heat the tab “Graphical simulation” or "Course of casting" displays graphically evolution of selected variables related to the sequence, heat and slab. In the tab "Prediction" by clicking on the button "Prediction rules" it is possible to select the set of prediction rules, and thus to perform the calculation (matching of prediction rules with the slab parameters and their visualisation). At the same time, if the limits are exceeded, possible - predicted defects affecting the quality of the slabs can be displayed.

During the casting of sequence after completion of casting of the heat all its slabs are numbered. In the tab "Prediction" it is possible to select the desired set of prediction rules and recalculation is performed for the given heat. After the recalculation the following screen is available in the program LITIOS, see Figure 6.

We can see in this screen, in addition to basic data on the sequence and the heat, an overview of all slabs. The heat is marked with a red cross in the event of a breach of some (any) of prediction rules for the heat at least in one section with a length of 1 meter of any of its slabs. Individual slabs are marked in the same way. Indication of fulfilment in the list of prediction rules is valid for the currently selected slab and it is related to the values of technological quantities of the rules for individual meters of the slab, which are also displayed. In the left part of the prediction rules the defects that may occur in the event of a breach of the rules are also displayed, as well as recommended data for handling with the slab. The prediction rules can be filtered out to only those that are defined as essential for quality control department, or it is possible to filter out only violated rules. As a complement to the displayed information it is possible to switch on a diagram showing in detail the evolution of technological variable of currently selected prediction rules, as it can be seen in Figure 6. Only the technological values of channels from thermal model are graphically displayed, because only these values are available in detailed form in small time intervals. Deviations from the FLS system are available only in an aggregated form per meter of the slab, that's why they are not displayed graphically. The diagram shows also the limit data (minimum, maximum) of the given rule for better explanatory power.

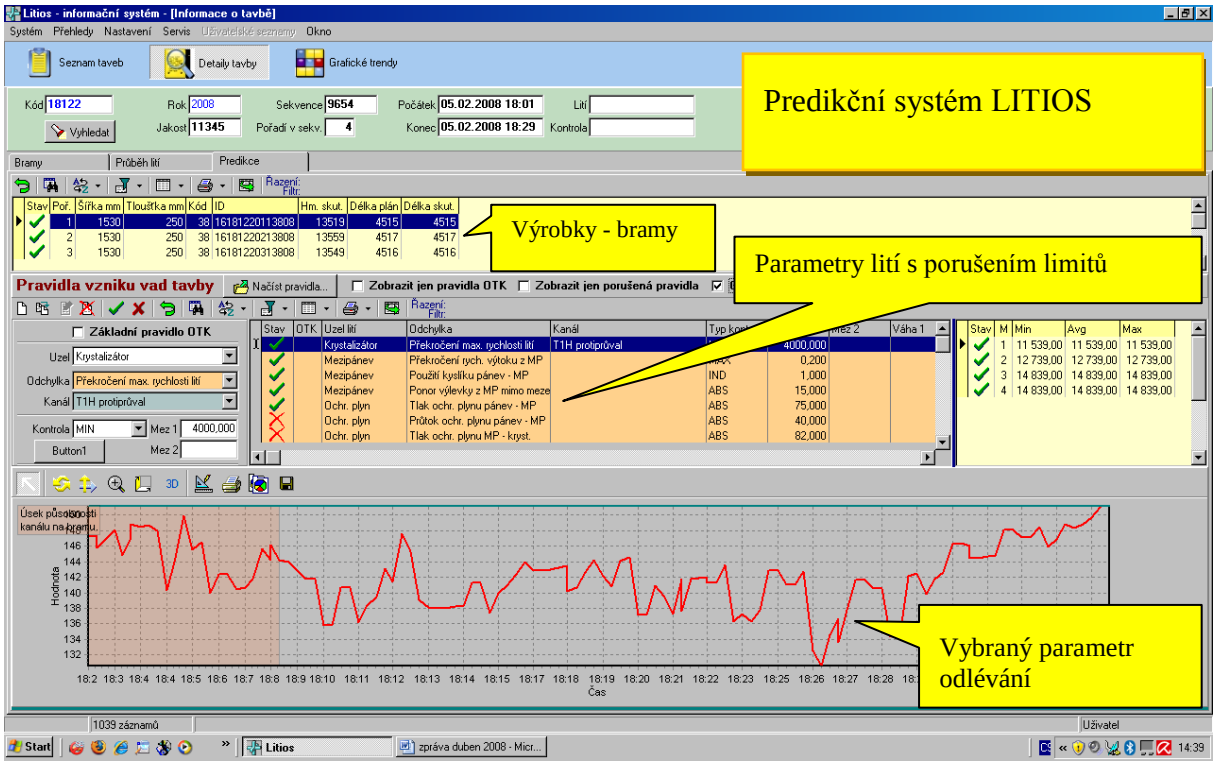



*Fig. 6. Tab Prediction*

The manner of prediction display and function described above is available for continuous casting technologists, as well as for the quality control department personnel and research staff. Due to the fact that the system has been deployed in the past year and that prediction is an extremely time-consuming process requiring also considerable human resources, its full utilisation and evaluation will still require further testing and evaluation. Currently, works are underway to simplify the prediction systems according to the requirements of the quality control department. Reflection of the prediction limits into the model is also under preparation.

## 8. CONCLUSIONS

After implementation of the program system LITIOS into industrial practice it serves also for operational control of production (the data and graphs serve as the source for daily meetings of the continuous casting shop management). In case of analyses of causes of defects on sheets the program serves as valuable source of data for subsequent statistical analyses. Results of statistical searches enable making of corrections of selected casting parameters, which should reduce the number of defects on slabs or even their elimination by selecting optimal values and limits of these parameters

This program system therefore fulfils the function of a comprehensive analytical software tool for evaluation and optimisation of production on continuous casting machine.

Results of procedures mentioned above are given in the literature sources [9], [10] and [11].

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