SCIENTIFIC PROBLEMS
OF MACHINES
OPERATION
AND MAINTENANCE
4 (156) 2008

BOLESŁAW KARWAT*

Analysis of materials' flow in a steel mill in order to determine exploitation parameters of technological line's devices

Key words

Optimisation the operation, scheduling process.

Słowa kluczowe

Optymalizacja eksploatacji, harmonogramowanie produkcji.

Summary

A raw steel mill is a continuous running complex production process in relation to used technologies. The above relates mainly to hot departments, such as furnaces or steel melting shops. Devices which operate in these departments are subjects to strict technological regimes. Any deviations from optimal operational parameters may cause non-reversible damages which shorten their operation time. The above relates mainly to furnaces, which can operate for several years, or a few, when their productivity is often limited. That is why, planning and scheduling the production process in a raw steel mill is an important issue for optimal devices operation and it is a difficult task as well due to production specific character.

This kind of running the production process forces deliveries to be on time and of the proper amount and set parameters components to devices of a production line.

Continuously running aggregates of steel founding are the superior devices in a production process and to which crude iron of set parameters, especially of set temperature and scheduled time, must be provided. To optimize the scheduling process, maximization of the quantity of casted items in a continuous sequence of production of steel casts from furnaces, must be considered as a criterion.

1. Technological system and production flow in a steel mill identification

The aim of the article is to identify a technological system and a production flow in a steel mill and to form basic principles of scheduling the production of

* AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Kraków.

such technological processes as [1, …, 16], to maximize the production process simultaneously with an optimal devices usage. The exemplary steel mill will be a subject of research conducting, its main objects and production flow scheme is presented in the Figure 1.

In the Figure 1 seven main subsystems of technological process in the steel mill are presented:

a) SP sintering plant – which produces iron – bearing sinter, which is a main component of crude iron in furnaces, where: 'a_k'=1,…,k; k-number of sintering lines;
b) BF furnaces – which produce crude iron for further processing in oxygen converters, with a possibility to found cast iron – its main components: sinter, coke, flux and hot air which initiate the reduction process, where: 'b_l'=1,…,l; l-number of furnaces;
c) HMDP desulfurization stations – enabling removing the sulfur excess from crude iron before processing in air converters, where: 'c_m'=1,…,m; m=desulfurization devices;
d) BOF oxygen converters – producing crude iron which is off-furnace processed – the basic components of the process are: furnaces' crude iron, steel scrap, ferroalloys, calcareous stone, where: 'd_n'=1,…,n; n=number of oxygen converters;
e) off-furnace stations, where crude iron enriching processes are conducted, in modern steel mills: AR-stations of crude steel argon-processing, LHF – ladleman off-furnaces processing, RH – steel vacuum circulation degassing, where: 'e_o'=1,…,o; o = off-furnaces steel processing devices;
f) CCM continuous steel founding aggregates, where crude steel is processed on continuous steel ignots – in modern steel mills 100% of crude steel is processed in this manner into blooms, billets, or slabs, where 'f_p'=1,…,p; p – number of continuous steel founding;
g) RM rolling , where ignots are processed into final (marketing) rolled products, where 'g_r'=1,…,r; r- number of hot-rolling technological lines.

Production scheduling is inferior to logistic view on the production system. In the figure 1 main logistic systems for researched object were presented:

① supply logistics;
② complete steel mill production logistics;
③ continuous hot processes production logistics;
④ market products distribution logistics;
⑤ waste material distribution logistics;

Market products distribution ④ is a superior issue of the logistics system. The logistics system information forces production planning (scheduling) and covers: ① supply logistics and ② complete steel mill production logistics.

In the Figure 1, the field of waste material distribution logistics was presented ⑤. This system is complex because of masses of waste material produced

in the production process. Nowadays in modern steel mills, the majority of waste material is completely recycled.

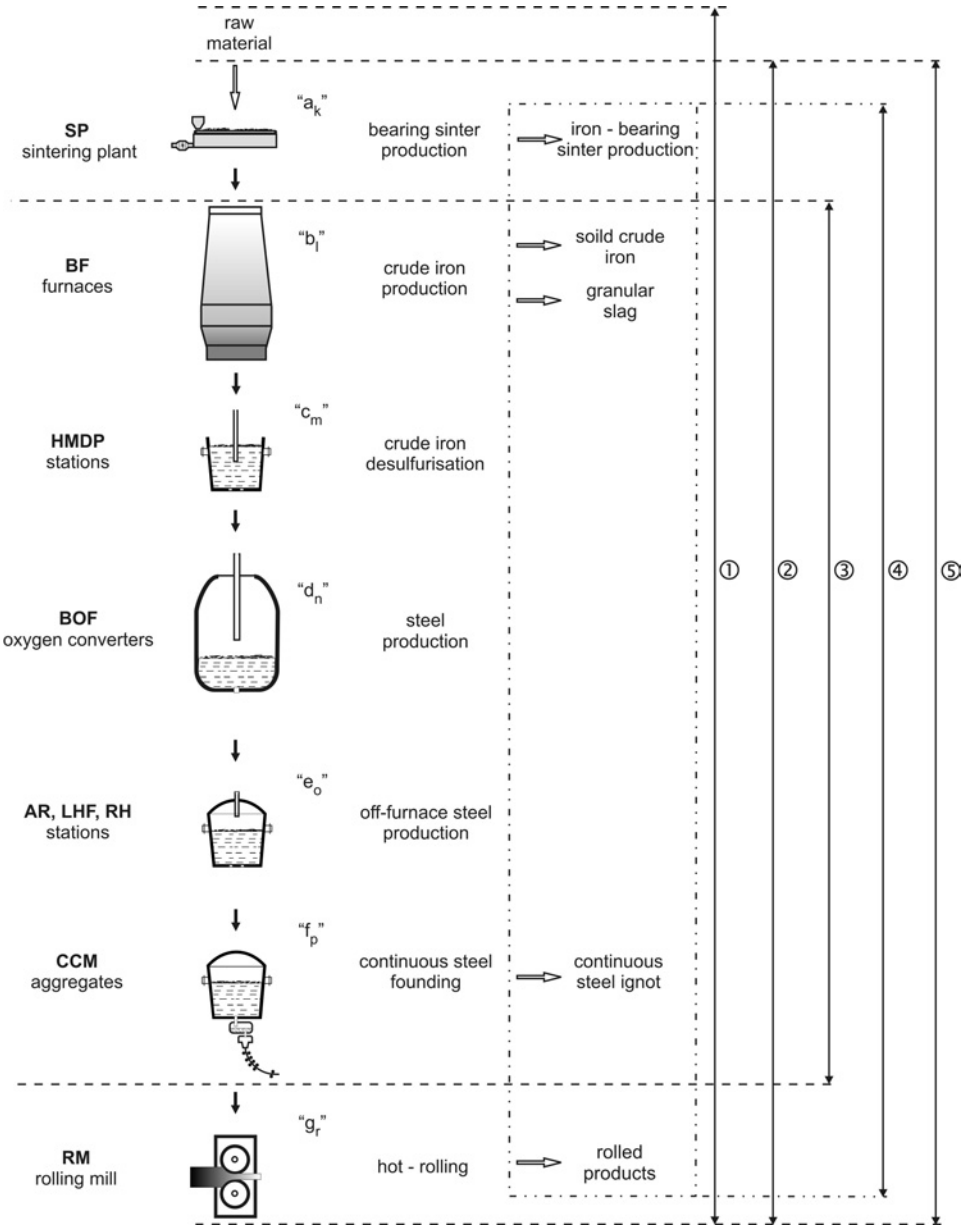

Fig. 1. Structural scheme of main technological objects in steel mill
Rys. 1. Schemat strukturalny głównych obiektów technologicznych huty surowcowej

The constructed model ought to cover all departments of a steel mill, starting from feedstock preparation to final products of rolling mill house, especially the following complex scheduling issues should be taken into consideration: hot processes production logistics ③.

In the Figure 1, the hot processes production logistic system covers furnaces, crude iron desulfurization, oxygen converters, off-furnaces processing and continuous steel founding aggregates. This system also covers departments of hot works, if the production optimization criterion will be delivered in a set time of continuous ingots with a set cross-section and temperature. This field of production scheduling may contribute to optimum usage of technological line devices, and lower the production costs in the same time.

2. Literature review

Many authors have tried to solve the production scheduling problem in steel industry taking advantage of various techniques of modelling these matters and various methods of solving them. Most of the world literature elaborates concern issues of production scheduling in plate mill departments.

Issues of production scheduling in plants in which manufactured products can be stored during the process operation are incommensurably easier than in case of a steel production plant in which the process has to be operated in a continuous manner. All production planning aid methods used in steel industry can be divided into two categories: methods based on mathematical programming and methods based on expert systems.

The literature analysis presented below comprises 30 selected items of world publications dealing with steel industry's production planning and scheduling. The analysis starts with elaborates published in 1974 and ends with elaborates published in 2007. All elaborates were presented chronologically as per their publishing dates.

One of the first elaborates on production planning and scheduling in steel plants was C.N. Redwine and D.A. Wismer [1] thesis dealing with arranging steel production's schedules in an "off-line" mode, not in a real-time, but with the use of a mathematical programming. The dynamic programming was used to solve the problem.

J.R. Wright and M.H. Hook [2] developed a heuristic procedure, which enabled generating schedules of hot rolled plates production. They defined an objective function, which represents an economic efficiency dependent on three contradictory conditions, such as: production's quality, production's speed, on-time supplies of finished products. The developed heuristic algorithm modifies given input solution through the "product" shift from the initial position to the other, more beneficial from a penalty function viewpoint. The penalty function consists of several selected parameters of the finished product. The algorithm

utilizes a trial-and-error method, up to the moment when further improvement is possible no more. The limitation of possibility of further improvement is given by the user. The method of schedule improvement finishes usually by achieving a local minimum.

B. Lally and others [3] applied a linear programming method, partially with the use of an integer programming to solve a problem of steel production scheduling and its processing to solid ingots in installations of continuous teeming. The authors developed a very simple steel plant's model, in which electric arc-furnaces and installations of continuous teeming are in operation. Complex processes of extra-furnace steel treatment, which are essential in enabling production of high quality solid ingots, were neglected in the model.

M. Numao, S. Morishita in their elaborates [4, 5, 7, 9] developed an expert system to plastic working scheduling in hot-rolling mills with the use of a graphical user interface which enabled modification of the previously created schedule. The main substantiation of such scheduling system was the limitation of feedstock latency time for the following technological operations, and therefore reduction of energy consumption in the whole rolling process.

H.P. Epp and others [6] in their elaborates presented a system of interactive production of scheduling for the installations of continuous teeming operating in Inland Steel Corporation, utilizing methods of artificial intelligence to solve the problem.

Y. Yimichi and others developed an expert system to determine parameters and conditions of slab bloom supplies obtained in the process of continuous teeming, in order to optimise the accomplishment of orders collected from recipients during hot-rolling process of these blooms.

C. M. Petersen and others [10] developed a mathematical programming model to solve the problem of hot-rolling plant production planning consisting of creating schedules for optimisation of solid ingots' passing through heating up furnaces and rolling mill's stands.

In their elaborate [11], K. Sthol, W. Spopek presented a model of hybrid cooperative production scheduling in the process of continuous steel teeming in Stahl Linz GmbH steel plant. However, they did not present a mathematical model for optimization of analysed processes.

J. Neuwirth [12] developed a model basing on linear programming, which eliminated the so- called machine conflicts arising during the treatment of the successive melts from steelmaking furnaces and the process of their teeming in installations of continuous steel teeming. The basic factors which enable creating schedules in the analyzed technological line were also formulated in the elaborate.

In their elaborate [13], X. Tong and others presented a complex model based on a linear programming method, partially integer, for solving the problem of solid ingots' production scheduling in installations of continuous steel teeming. The solution of this problem was possible through the use of heuristic techniques.

In his elaborate [14], P. Cowling describes the issue of generating a production plans for a hot-roll plate mill. A matter was described as a problem of searching for "a route with a reward". To solve this task, the author proposed a heuristic method, which was based on searching for local solutions and looking for "Tabu Search". The local search method is used to find an input sequence, and the "tabu" search technique aims at improving this sequence. The author analyzes obtained results in various aspects and in all cases the results obtained with the use of applied heuristics are better than traditional methods used so far in solving this type of problems.

In their elaborate [15], K. Hamada and others presented an algorithm for solving complex problems of steel production planning and subsequently merged an expert system with genetic algorithm, and created effective schedules in this way.

In their elaborate [16], H. S. Lee and others described a production planning procedure in a double-wire installation of continuous steel teeming. They utilized the IBM and ATM software to create schedules meeting global limitations based on a fast task ordering algorithm.

In their elaborate [17], L. Lopez and others used a heuristic method based on problem approach as a "tabu search" to solve the problem of production scheduling in a hot-rolling plate mill. The problem of rolling plate mill production scheduling is very difficult and comprises series of mutually contradictory objectives, which have to be achieved with taking into consideration series of restrictions. Finding an optimal solution for this problem is very difficult, therefore authors were satisfied with finding suboptimal solutions.

In their elaborate [18], S. Li, Z. Chan describes the materials' flow through buffer stockyard of solid ingots produced in the process of continuous steel teeming and a hot-rolling plant. Basing on data from the analyzed steel plant, the authors created a mathematical model describing a decision making process of system input, system output and storage in the system. The created model appeared to be very effective and was used as a system simulating the production flow management in the existing steel plant.

In their article [19], P. Cowling, W. Rezig presented an integration model of a continuous steel teeming and hot-rolling system in order to maximize the production and lower unit production costs. Authors described the currently used methods of production planning and presented a model of production planning and scheduling in the analyzed system with the use of mathematical programming and heuristic techniques. The described method, as it arises from performed simulations, is close to an optimal, and has been implemented in many steel plants.

The subject of an elaborate of L. Tang and others [20] was to study a problem of production planning in processes of continuous steel teeming and pursuit of creating a computer-based planning system in order to generate optimal schedules. The objective of schedules is to determine task commencement and

finishing times on the successive installations of a technological line. The objective function in an optimization process is to deliver the product to the following operations precisely on time, in accordance with the JIT rule. Penalties were also incorporated in the model: for losses caused by a heat stoppage, treatment latency time, too early operation accomplishment, delay in operation accomplishment. The developed non-linear mathematical model for solving the machine conflict problem was consecutively replaced by a linear programming model. Computer simulations with the use of standard computer software demonstrated a meaningful reduction of following operation latency times when using schedules created this way.

In their article [21], F. Pettersson and others presented the system for optimal planning of flat solid ingots production based on a double method of linear programming with the use of integer programming and heuristic algorithms. The created system formulates a way of task clustering and a sequence of flat blooms teeming in the installation of continuous steel teeming.

In their article [22], L. Tang and others presented a model of production scheduling in a hot-rolling plate plant. In the elaborate a strategy parallel to a production scheduling problem modelling was proposed as well as a solution of the matter through of the use of genetic algorithms. The adopted algorithms and the use of an interactive machine-human method caused a meaningful development of the proposed method in relation to the manual method used before in the analyzed steel plant.

Authors of the elaborate [23], L. Tang and others, tried to find a solution for increasing production efficiency and lowering energy consumption in a technological line containing installations of continuous flat blooms teeming, their heating up and hot-rolling. The developed algorithms of production planning and scheduling enable such energy consumption limitation in the analyzed technological line.

Authors of the elaborate [24], V. Jha and others, made an attempt to create an intelligent production planning and scheduling algorithm for steel teeming processes in LD oxygen converters and flat blooms teeming in installations of continuous steel teeming. The G2 computer software was used for this purpose. The created algorithms aim at lowering production costs, increasing products' quality and delivering the product in a precisely defined time.

In their article [25], L. Tang and others introduced the proposal of solving the problem of scheduling the transport of slabs having strictly specified parameters, which are produced in installations of continuous steel teeming, to hot-rolling plate plants. For this purpose an algorithm based on integer methods was formed, which consecutively was modified into a genetic algorithm. Codes used for the genetic algorithm aimed at minimizing the awaiting tasks solving time. Within a framework of performed studies, the authors implemented the constructed model in an existing plant achieving positive effects in the scope of assumed objective function.

In their elaborate [26], Z. Gao, L. Tang present studies on forming an effective optimization model, which uses methods of multiparameter pointwise sum weights approximations. The developed method was used to plan purchasing materials for production in a raw steel plant in order to determine their optimal quantity. The problem examined in the elaborate is substantial because of the mass character of raw materials necessary for production in the production plant such as steel plant.

In their article [27] SH. Park, YW. Sohn present a heuristic method of minimization of the successive technological operations latency time in steel production processes, continuous steel teeming and hot-rolling. Authors developed the system aiming for a real-time production scheduling taking into consideration the necessity of changes in a technological process by effective use of a human-computer communication. Limitations arising from technological processes in operation were taken into account in the used algorithms so as to maximally reduce the latency time of the successive processing of a given cast.

In their elaborate, L. Tang, L. Huang [28] present studies on the seamless steel pipes production scheduling. The problem has been presented as a sequence flow scheduling in order to minimize times between start and completion of the hot-rolling process. The authors look for a suboptimal solution using a double-stage method of sectioning and limitation and heuristic algorithms. Study results confirmed, that with the use of such algorithms one can obtain a solution close to optimal.

The elaborate of M. Mathirajan and others [29] refers to a study problem of task scheduling with the use of parallel, non-identical initial processes for a dynamic task income, non-compatible task series and non-equal task quantities. Task scheduling in heat treatment processes has an essential meaning for the entire steel casting production times. In order to restrict the amount of performed calculations in classical mathematical models, several heuristic algorithms were developed, which enabled obtaining suboptimal solutions in the scope of utilization of furnaces in a heat treatment.

The elaborate of L. Tang, G. Liu [30] refers to scheduling of production orders in a steel plant in order to determine a particular technological operation start and finish times with efficiency limitations, with a purpose to minimize the sum of weighted times of all orders' finishing. This problem was formed as a question of mixed integer programming. To solve the problem the methodology of solving the distribution composed of Lagrange relaxation, linear programming and heuristics was used.

In the analyzed world literature there are no elaborates concerning the production scheduling for the whole raw steel plants from the raw material supply through material preparation facilities, departments of pig iron production, departments of steel production and its extra-furnace treatment, installations of continuous steel teeming, up to final product rolling mills.

3. Analysis of technological processes and material flow in main departments of the steel mill

In the Figures 2-6 five main departments of the steel mill is presented. In the Figure 2, sintering plant SP is shown, where preparation of iron-bearing sinter with set parameters, especially its granulation, is made. It also considers coke, which is used as a reducer in the furnace process. This parameter is a main factor of a proper work of furnaces. Sintering process is preceded by a compound preparation in the field of its homogenity of chemical composition, and then the composition is granulated. The last phase of the process is sintering, which is conducted on three sintering lines of 312 [m^2] surface and 1000––1250 [kg/m^3 x h] productivity. The sinter is cooled on the same line and in whirling cool stores after completing the process and transported to foundry - mixture store department. Parameters of all ingot components and a ready sinter, as well as devices work parameters in sintering store were given in the Figure 2.

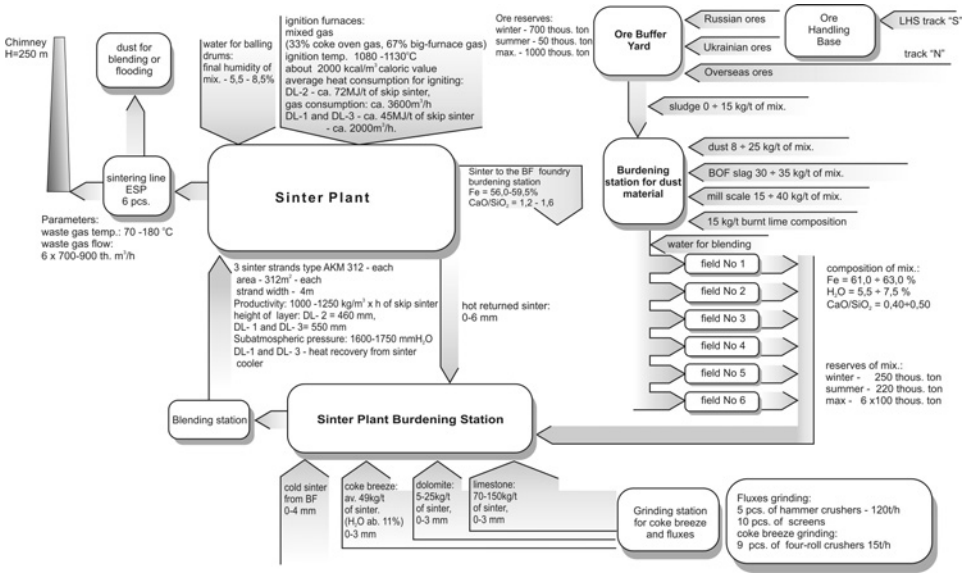

Fig. 2. Scheme of technological processes and material flow in sintering plant (SP)
Rys. 2. Schemat procesów technologicznych i przepływu materiałów w spiekalni rud (SP)

Figure 3 presents a scheme of furnaces department (BF), which consists of three main objects, furnaces and the essential infrastructure to enable the crude iron production as a steel production intermediate product. The researched object consists of two furnaces, which are of 3200 [m^3] volume and 2,4 [millions tones/year] productivity, and one thoroughly renovated in the renovation process of 3600 [m^3] volume and 2,8 [millions tones/year] productivity. Sinter

chemical composition homogenity guarantees the comparable chemical composition with every heat melt. During the heat mill there is a sample taken and before reaching the steelplant, the chemical composition, mainly coal content, but also the other impurities such as sulfur, manganesse, silicon, phosphorus and other, is known. In the researched steel mill, in the furnaces departments, there are two pig sow founding devices with productivity of 2000 [t/24h], in case when steelplant cannot manage to process the produced crude iron, and there are outer receivers. The flow of input materials and production, and their main parameters and parameters of basic devices used in the department are shown in the Figure 3. The furnace department is the first phase of the hot technological lines, where the processing cannot be stopped. Iron-bearing sinter is considered to be a furnace ignot, while, coke is a reducer and a hot blast, which initiates the crude iron sinter process. The hot blast is produced in Cowper stove, four per each furnace. Furnace crude iron as iron and coal alloy of 3,5 – 4,5% [C] coal content is a final product. Slug is a waste material product, which is thoroughly processed in cement production. Furnace gas is another waste material reused to heat the heaters' air and other, because of its energetic value:

Figure 4 presents a scheme of Steel Plant Department (SPD), which is divided into four groups of devices presented in the Figure 1 as:

- (HMDP) – stations for raw iron desulfurization with a productivity of 6 [millions tones/year];
- (BOF 1, BOF 2, BOF 3) – three oxygen converters with a maximal capacity of 350 [tones], with BOF 1 and BOF 3 working in the upward blast system with the use of an oxygen lance and downward through gas permeable ceramic bricks; and BOF 2 with an upward blast only;
- (AR1, AR2, AR3, AR4) – four liquid steel argoning stations;
- (LHF 1, LHF 2) – two ladle furnaces for a thorough off-furnace processing, LHF 1 – 1station ladle furnace, LHF 2 – 2stations ladle furnace with a movable electrodes system for liquid steel heating;
- (RH) – a station for vacuous degassing of selected kinds of liquid steel;
- (OBR) – ladle turn-around table with a liquid steel to set the ladles on turn-around continuous steel casting towers (WO1, WO2, WO3);
- (CCM 1, CCM 2, CCM 3) – three continuous steel casting aggregates, CCM 1 and CCM 2 for rounds and billets casting, and CCM 3 for slabs casting for external receivers.

In the Figure 4 other feedstock material flows were presented, such as feedstock strap, loose material, including ferroalloys and lime preparation in Maerz furnaces. Possible relations between particular devices of the technological lines (SPD) and basic parameters of those devices, were presented in the figure.

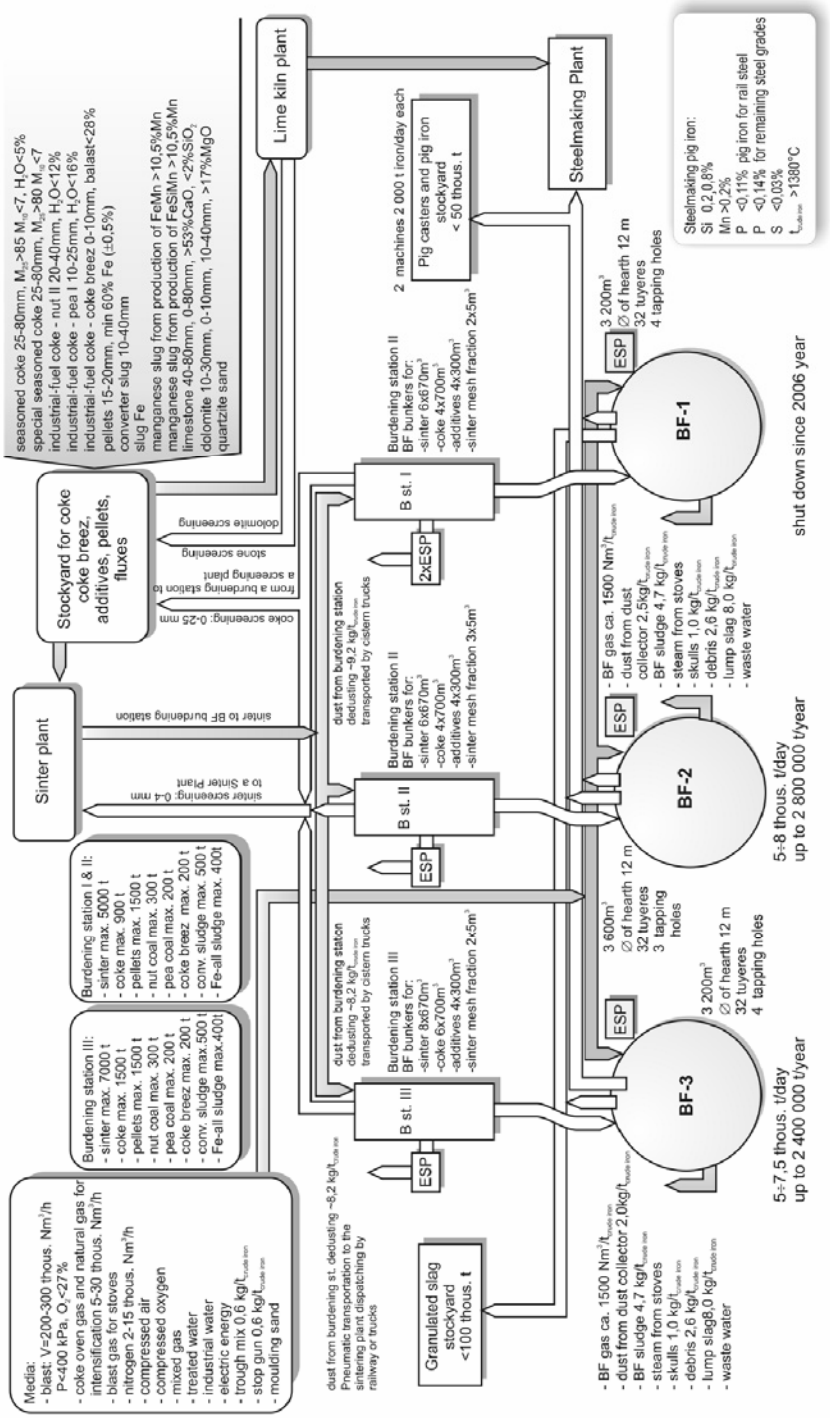

Fig. 3. Scheme of technological processes and material flow in Furnaces Department (BF)
Rys. 3. Schemat procesów technologicznych i przepływu materiałów w wydziale Wielkich Pieców (WP)

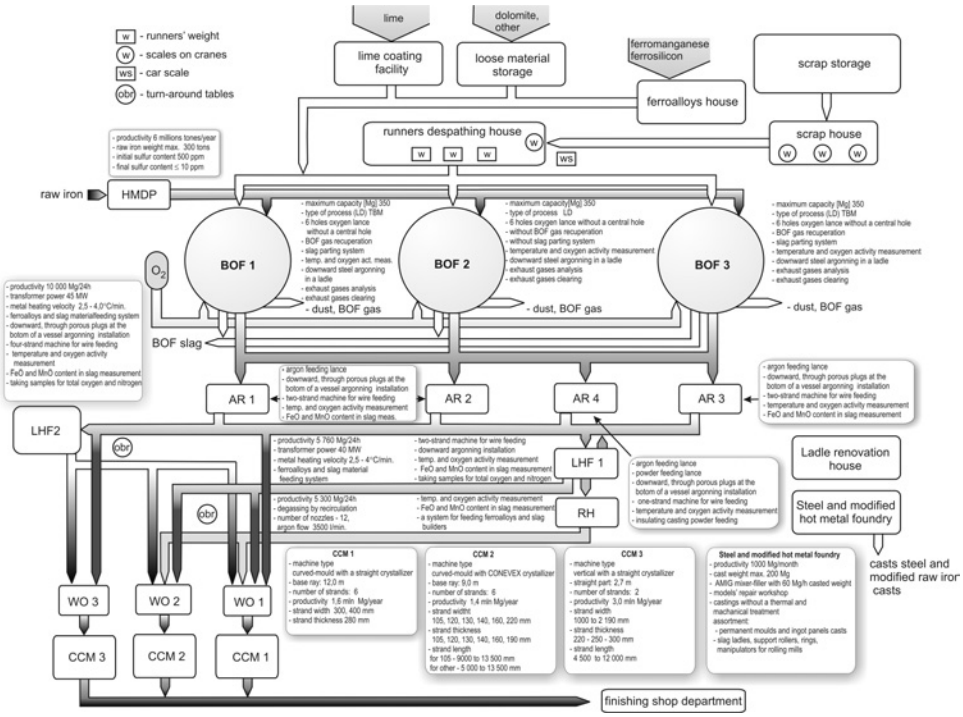

Fig. 4. Scheme of technological processes and material flow in Steel Production Department (SPD)
Rys. 4. Schemat procesów technologicznych i przepływu materiałów w Zakładzie Produkcji Stali (ZPS)

On the scheme of the Steel Production Department all possible transitions between technological line devices were shown, particularly concerning transitions between oxygen converters from off-furnace processing to continuous casting aggregates. Semi products are mainly transmitted to other concern facilities, but also to external receivers and two rolling mill houses of hot final products.

Figure 5 shows the scheme of thick profiles hot-rolled rolling mill house technological line (RM I) with productivity of 1,2 millions [tones/year]. The rolling mill house produces five groups of rolled sections described as $y_1, \ldots, y_5$ in the figure, which can be produced in the range of 120 profile dimensions. Technical parameters of main devices of the technological line were presented.

Figure 6 presents the scheme of rolling mill house (RM II) with the hot rolled profiles productivity of 0,815 millions [tones/year]. The rolling mill house produces 4 groups of sections described in the picture as: $x_1, \ldots, x_4$, which can be produced in the number of 120 profile dimensions. In the picture there were also shown the technical parameters of main devices of the technological line.

The number of hot rolled final products, profile dimensions (together about 240), in both rolling mill houses is so high, that the orders receiving and grouping system must be computerized, which allows to plan the production to shorten the order realization time and to fully use the productive abilities of the whole technological system.

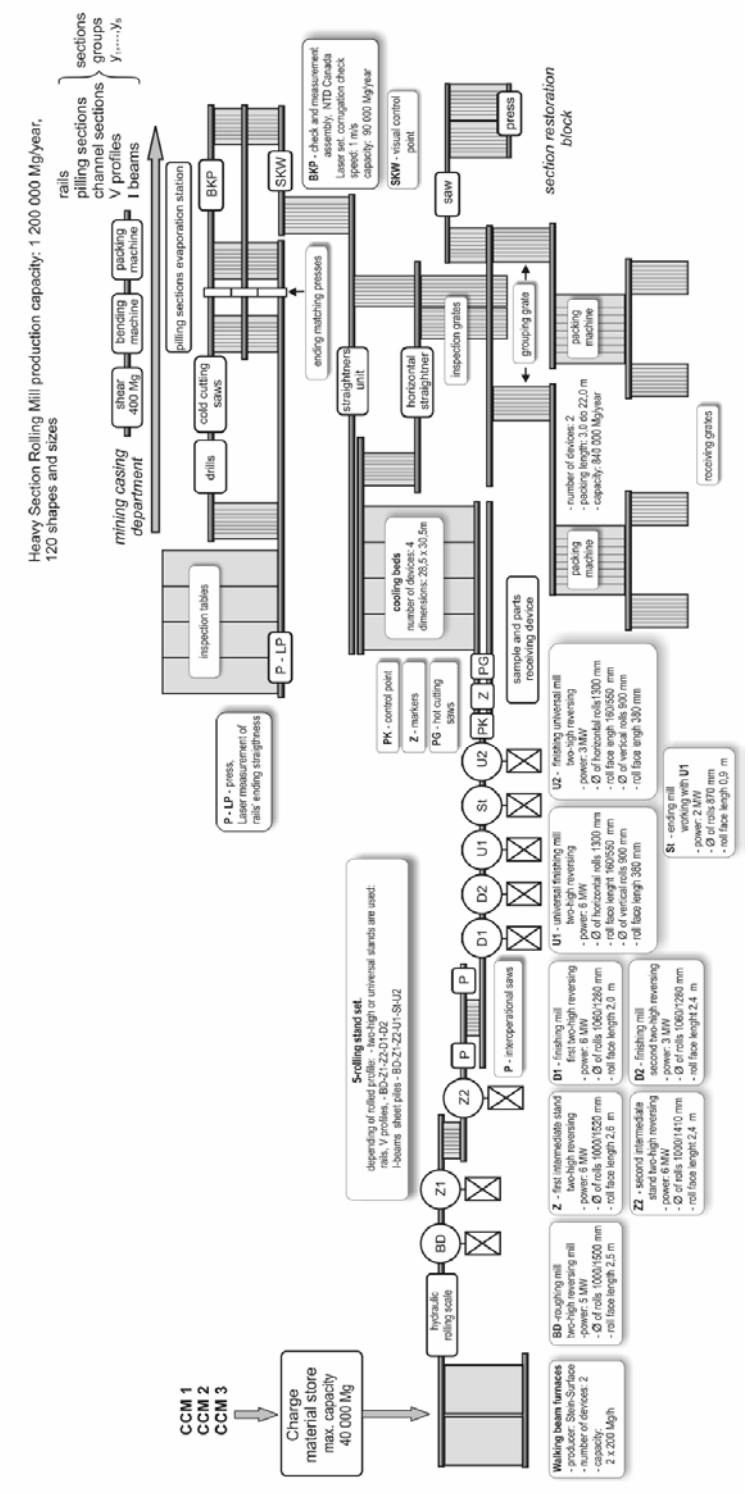

Fig. 5. Scheme of technological processes and material flow in rolling mill house I (RM I)
Rys. 5. Schemat procesów technologicznych i przepływu materiałów w Walcowni I (WL I)

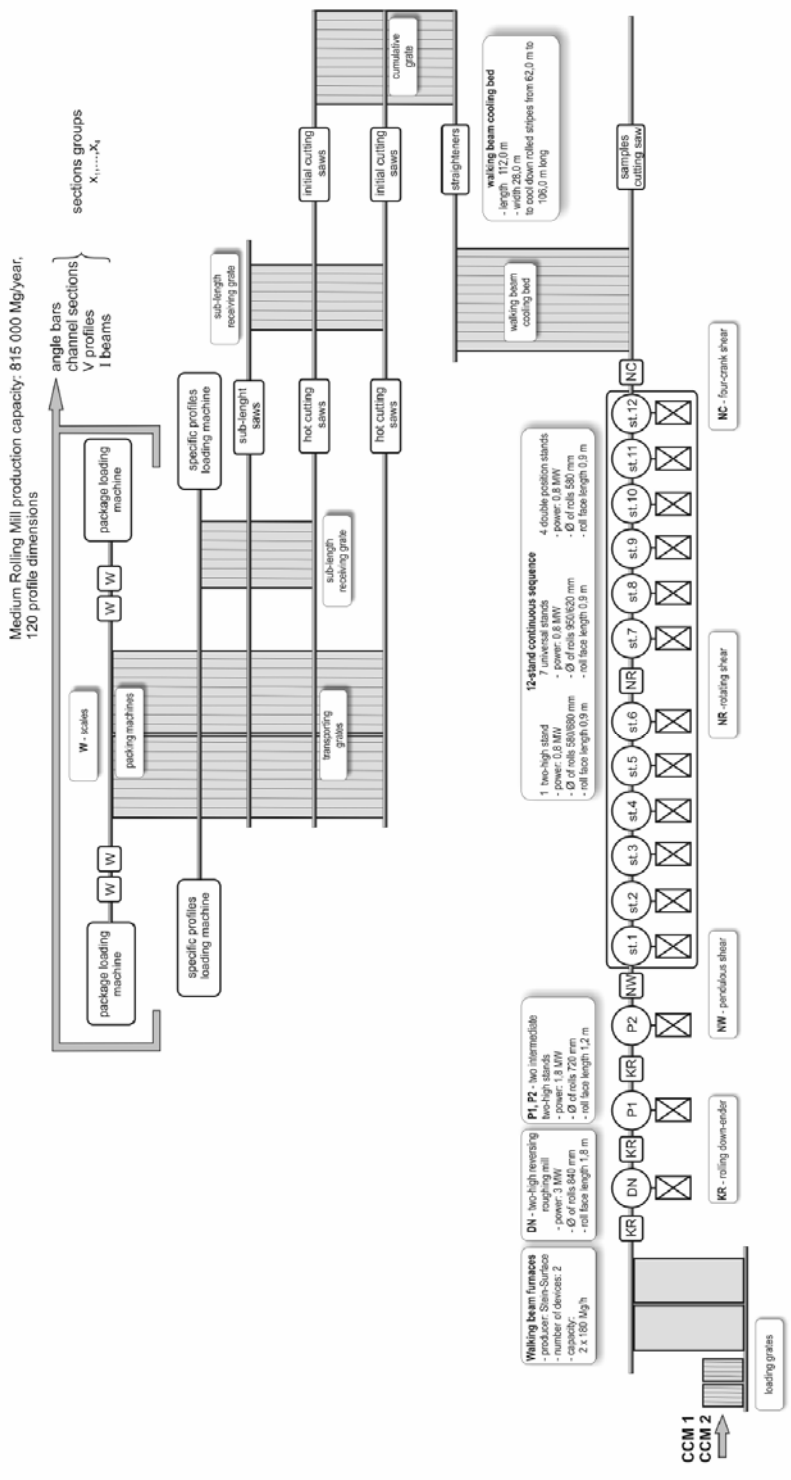

Fig. 6. Scheme of technological processes and material flow in Rolling mill house (RM II)
Rys. 6. Schemat procesów technologicznych i przepływu materiałów w Walcowni II (WL II)

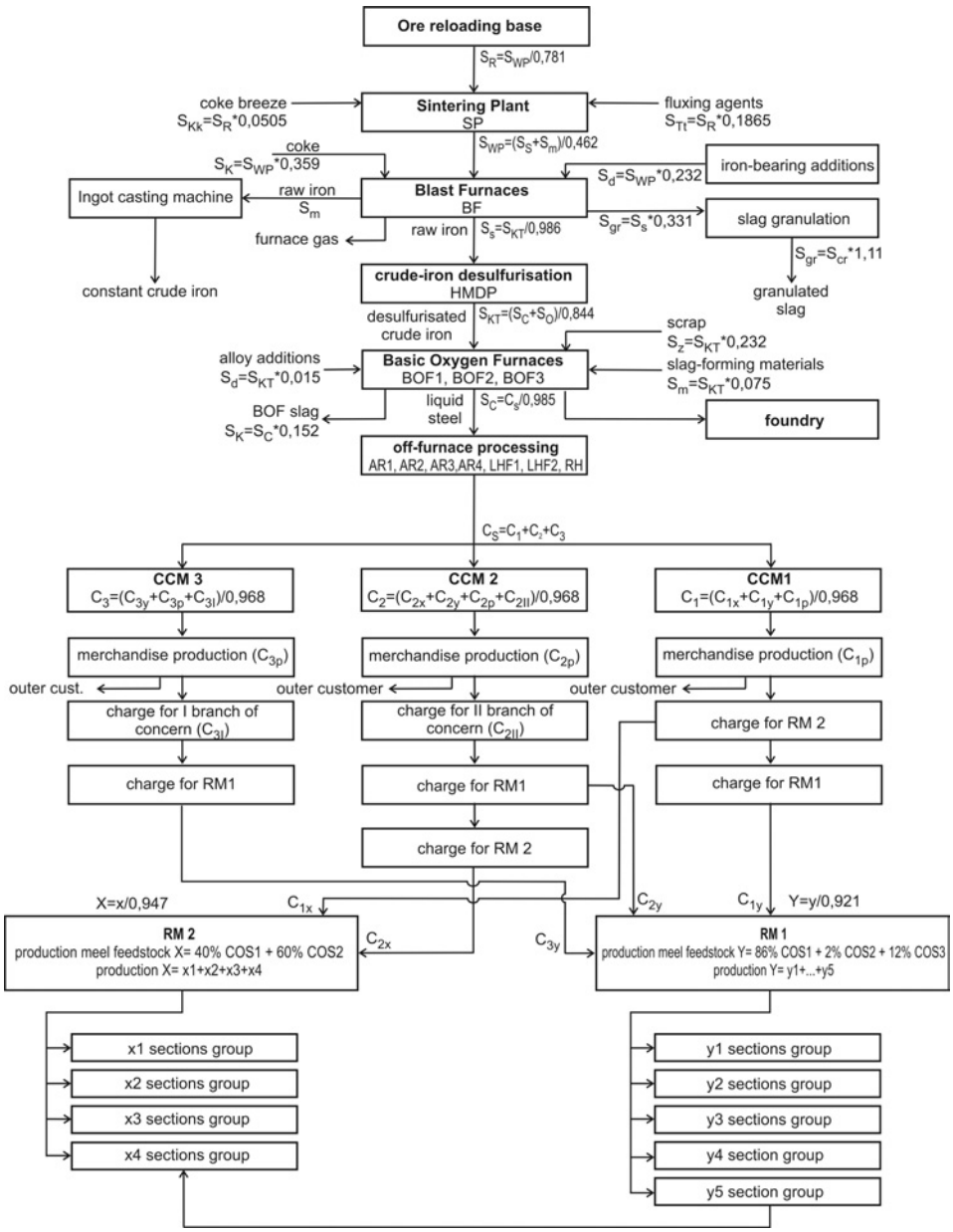

Fig. 7. Scheme of material flow and production in main departments of steel mill
Rys. 7. Schemat przepływu materiałów i produkcji w głównych wydziałach huty surowcowej

4. Quantitive research of production flow in the steel mill

On the basis of statistic research conducted in various phases of production in the researched steel mill, there were an algorithm evolved, which enables to calculate material and raw material demand for production process of ordered final products realization. Figure 7 presents an algorithm, where final rolled products were marked as RM I sections' groups (y_1, ..., y_5) and RM II sections' groups (x_1, ..., x_4), and CCM aggregates continuous ingots for external receivers, and continuous ingots for other receivers of the concern's branches. Yeilds' values for particular phases of the production process allow to calculate at any time a demand for a half-product from any device with strictly assessed final product demand. In the figure 7 all possible transfers between continuous steel casting aggregates in Steel Production Department and final products of RM I and RM II rolling mill houses were shown. According to the analysis, half-products for RM II are delivered only from CCM 1 and CCM 2, while for RM I, from all three aggregates and there is only a few percent of products from CCM 3. CCM 3 aggregate works mainly for other branches of the concern and for outer receivers. CCM 3 aggregate produces slabs, which are half-products for hot-rolled sheets, and this kind of rolling mill house was not analyzed.

5. Summary

Analysis and technological processes course identification in the steel mill, and data concerning main devices of particular departments, will enable to conduct the further detailed research about material flow and specific processes time of realization. Firstly, Steel Production Department ought to be analysed, due to the fact that its continuous steel casting aggregates determine the work of the Rest of the devices. Moreover, Furnaces Department also ought to be analysed, because it is responsible for delivering the set amount of crude iron in the set time. Furnaces' survivability is influence with the proper exploitation. The length of exploitation influences the fixed costs, and the steel mill earning capacity in the same time. The detailed analysis of hot departments' work will allow to prepare the scheduling system for the most complicated part of steel mill work. Production planning and scheduling of this steel mill production system requires giving consideration to many factors. Scheduling process for short periods of time is complicated, but only some elements of technological processes have to be taken into account. Issues connected with devices' different exploitation times in the technological process also need to be taken into consideration while long term scheduling.

References

[1] Redwine C.N., Wismer D.A.: A Mixted Integer Programming Model for Scheduling Orders in a Steel Mill. Journal of Optimization Theory and Applications.Vol.14, No.3, New York, 1974.

[2] Wright J.R., Houck M.H.: An application of systems modeling in steel production scheduling. Emgineering Software IV, Proceedings of the Fourth International Conference, Kensington Exhibition Center, London, 1985.

[3] Lally B., Biegler L., Henein H.: A Model for Sequencing a Continuous Casting Operation to Minimize Costs. Iron end Steelmaker. No. 10, 1987.

[4] Numao M., Morishita S.: SCHEPLAN – A scheduling expert for steel-making process, in: Proceedings of the International Workshop on Artificial Intelligence for Industrial Applications, Hitachi, 1988.

[5] Numao M., Morishata S.: A scheduling environment for steel-making processes, in: The Fifth Conference on Artificial Intelligence Applications, Washington, DC, USA, 1989.

[6] Epp H.P., Kalin M.G., Miller D.P., Karwan K.R., Sweigart J.R.: An integrative adaptive, real-time scheduler for steel-making, in: Proceedings of the Third International Conference. Expert Systems and the Leading Edge in Production and Operations Management, USA, 1989.

[7] Morishita S., Numao M., Tozawa Y.: A scheduling expert for steel-making process by cooperative scheduling. Journal of Japanese Society for Artificial Intelligence 5, 1990.

[8] Yimichi Y., Hori H., Odira T.: An expert system of automatic slab assignment for hot strip mill. ISIJ International 30 (1990).

[9] Numao M., Morishita S.: Cooperative scheduling and its application to steel-making processes. IEEE Transactions on Industrial Electronics 38, 1991.

[10] Petersen C.M., Sorensen K.L., Vidal R.V.V.: Inter – process synchronization in steel production. International Journal of Production Research Vol.30, No. 6, 1992.

[11] Sthol K., Spopek W. VAI-Schedex: A hybrid expert system for co-operative production scheduling in steel plant, D.K. Baik (Ed.). International Conference on Computerized Production Control in Steel Plant. Korea, 1993.

[12] Neuwirth J.: A production scheduling system at the Stahl Linz GmbH, in: D.K. Baik (Ed.). International Conference on Computerized Production Control in Steel Plant. Korea, 1993.

[13] Tong X., Silverman J., Clausen S.: A caster sequencing optimization program for Geneva Steel's Facility Modernization project. Presented at Annual AISE Convention, September 1994.

[14] Cowling P.: Optimization in steel hot rolling. Wiley, NY, 1995.

[15] Hamada K., Baba T., Sato K., Yufu M.: Hybridizing a genetic algorithm with algorithm with rule based reasoning for production planning. IEEE Expert 10, 1995.

[16] Lee H.S., Murthy S.S., Haider S.W., Morse D.V.: Primary production scheduling at steel-making industries. IBM Journal of Research and Development 40, No. 2, 1996.

[17] Lopez L., Carter M.W., Gendreau M.: The hot strip mill production scheduling problem: A tabu search approach. European Journal of Operational Research 106, 1998.

[18] Li S., Chan Z.: Mathematical models of logistics decision in slab yard in an iron and steel complex. Journal of University of Science and Technology Beijing (English Edition) (China), vol. 7, No. 4, Dec. 2000, ISSN 1005-8850.

[19] Cowling P., Rezig W.: Integration of continuous caster and hot strip mill planning for steel production. Journal of Scheduling. No 3, 2000.

[20] Tang L., Liu J., Rong A., Yang Z.: A mathematical programming model for scheduling steelmaking – continuous casting production. European Journal of Operational Research 120, 2000.

[21] Pettersson F., Slotte M., Haggblad T., Koistinen J., Saxen H.: A system for optimal melt shop production planning. 84th Steelmaking Conference, Baltimore, MD, USA, 25-28 Mar. 2001. Iron and Steel Society/AIME, 84th Steelmaking Conference. Proceedings (USA), 2001, ISBN 1-886362-53-X.

[22] Tang L., Liu J., Rong A., Yang Z.: A multiple traveling salesman problem model for hot rolling scheduling in Shanghai Baoshan Iron & Steel Complex. European Journal of Operational Research 124, 2000.
[23] Tang L., Liu J., Rong A., Yang Z.: A revive of planning and scheduling systems and methods for integrated steel production. European Journal of Operational Research 133, 2001.
[24] Jha V., Mahashabde V., Mathur VK., Karunakar AN.: G2 - a shop scheduling tool for LD 2 and slab caster. Tata Iron and Steel, Tata Search (India), 2002, IS: ISSN 0971-5975.
[25] Tang L., Liu J., Rong A., Yang Z.: Modelling and a genetic algorithm solution for the slab stack shuffing problem when implementing steel rolling schedules. International Journal of Production Research. Vol. 40, No. 7, 2002, ISSN 0020-7543.
[26] Gao Z., Tang L.: A multi-objective model for purchasing of bulk raw materials of a large-scale integrated plant. International Journal of Production Economics. Vol. 83, 2003.
[27] Park SH., Sohn YW.: The Development of Synchronized Scheduling System for Steel Making & Hot Rolling Process RIST Journal of R&D (South Korea), vol. 17, no. 2, June 2003, ISSN 1225-486X.
[28] Tang L., Huang L.: Optimal and near-optimal algorithms to rolling batch scheduling for seamless steel tube production. International Journal of Production Economics. Vol. 105, 2007.
[29] Mathirajan M., Chandru V., Sivakumar A.I.: Heuristic algorithms for scheduling heat-treatment furnaces of steel casting industries. Sadahana, Vol. 32, Part 5, 2007.
[30] Tang L., Liu G.: A mathematical programming model and solution for scheduling production orders in Shanghai Baoshan Iron & Steel Complex. European Journal of Operational Research 182, 2007.

This scientific work was financed by the Ministry of Science and Higher Education as a research project No N N504 407235.

Manuscript received by Editorial Board, January 12th, 2009.

Analiza przepływu materiałów w hucie stali w celu określenia parametrów eksploatacji urządzeń ciągu technologicznego

S t r e s z c z e n i e

Huta surowcowa stali jest bardzo skomplikowanym systemem produkcyjnym pod względem realizowanej technologii, pracującym w systemie pracy ciągłej. Dotyczy to w szczególności wydziałów gorących, takich jak wielkie piece i stalownia. Eksploatowane w tych wydziałach urządzenia podlegają bardzo ścisłym reżimom technologicznym. Wszelkie odchylenia od optymalnych parametrów eksploatacji tych urządzeń i powodują nieodwracalne uszkodzenia skutkujące skróceniem czasu ich pracy. Szczególnie dotyczy to wielkich pieców, które mogą pracować nawet kilkanaście lub kilka lat w przypadku, kiedy często w okresie eksploatacji jest ograniczana ich normalna zdolność produkcyjna. Dlatego też planowanie i harmonogramowanie produkcji w hucie surowcowej jest zagadnieniem niezwykle istotnym dla optymalnej eksploatacji urządzeń, a jednocześnie bardzo trudnym ze względu na specyfikę produkcji. Takie prowadzenie procesu technologicznego wymusza dostarczanie w ściśle określonym czasie odpowiedniej ilości półproduktów o ustalonych parametrach, do kolejnych urządzeń ciągu technologicznego. Nadrzędnymi urządzeniami w ciągu technologicznym są agregaty ciągłego odlewania stali, do których musi być dostarczana ciekła stal o określonych parametrach, szczególnie w zakresie jej temperatury i w określonym przez harmonogram produkcji czasie. Do optymalizacji procesu harmonogramowania należy przyjąć jako kryterium maksymalizację ilości odlanych bez przerwy w sekwencji wytopów stali z pieców stalowniczych.