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Production scheduling in a steel working plant

K e y w o r d s

Production scheduling.

S ł o w a k l u c z o w e

Harmonogramowanie produkcji.

S u m m a r y

A steel working plant is a complex production system where the processes are performed on the continuous basis. The process starts with raw materials: iron ore, carbon, limestone, and others and end with final rolled products. Production scheduling in such complex systems is a formidable task. Research work to date has been restricted to the selected plant departments or processes [5-11, 17, 20, 21]. Ensuring the continuous, uninterrupted operations of so-called 'hot' sections requires that time regimes be precisely controlled, which means that the pertinent schedules have to be worked out, starting from material supply and preliminary treatment, passing through all process plants, right through to finished articles.

1. Introduction

Steel working plant production system consists of variety of complex technological devices with various technological process realisation times, and

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transport devices, which enable the realisation of performed technological processes. The production system of steel working is shown in figure 1.

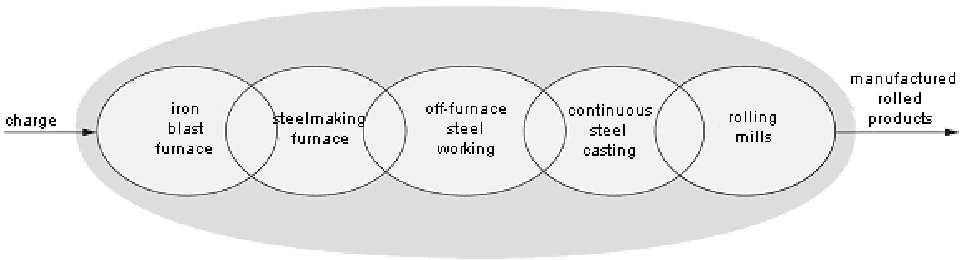

Fig. 1. Steel working plant's production technological line diagram
Rys. 1. Schemat ciągu technologicznego produkcji w hucie surowcowej

The diagram shown in Fig. 1 consists of five main subsystems, which are structurally connected to one another. Four of these subsystems, i.e. iron blast furnaces, steelmaking furnaces, off-furnace steel processing and constant steel casting aggregates are the "hot sections." They operate in a continuous mode with no stopping possibility and are interconnected with one another in a special way, as far as semi-finished products supply scheduling from one subsystem to another are concerned. It particularly concerns the supply of liquid steel to continuous casting aggregates at the required moment.

The most important factor distinguishing the steel products manufacturing process is the divergent "fork" characteristic of material flow in the steel working plant. In each stage of manufacturing process, the stream of materials is divided into two or more streams. The production characteristics of steel working plant disable the use of known logistic methods and tools assisting production processes scheduling used in other industry branches.

In order to optimise the efficiency of the production system, it is necessary to ensure constant material and semi-finished products supply for each stage of the technological process. The diversity of products, considering shapes and dimensions, as well as grades of steel, leads to different passage times for individual products. Determination of realisation times for individual tasks causes difficulties due to the existence of coincidences of various batches of semi-finished products to be worked on at the same devices (creation of "machine conflicts") and the necessity to select sequences in which the operations will be performed.

2. Production system identification

The aim of this article is to identify production flow system in a steel working plant, and based on this identification, to form the general production scheduling rules for such technological lines. The model steel working plant will be the subject of the research. The diagram in Figure 2 shows the main technological devices and production flows between them for the model steel working plant.

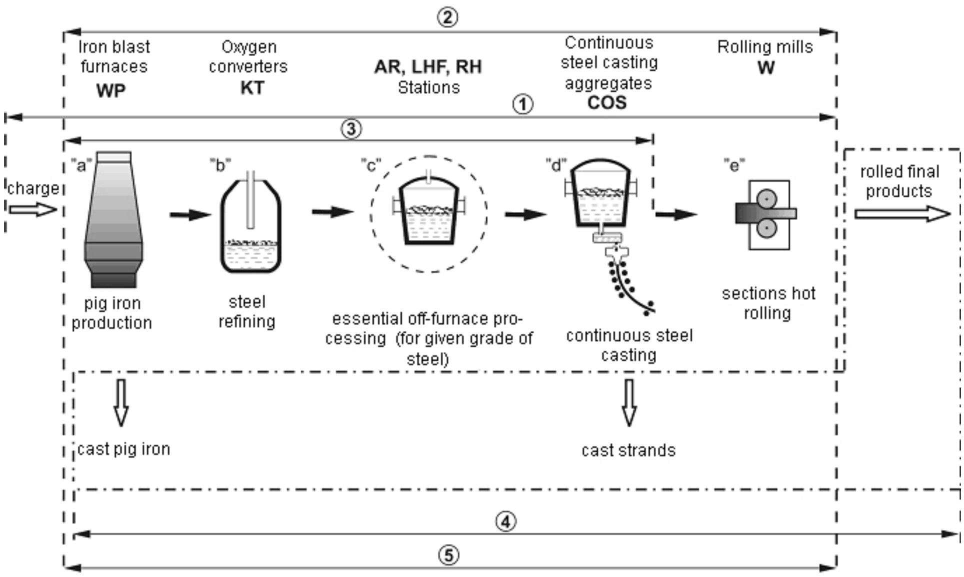

Fig. 2. Structural diagram of main technological devices of steel working plant
Rys. 2. Schemat strukturalny głównych obiektów technologicznych huty surowcowej

Fig. 2 shows five main subsystems in steel working plant's technological line, i.e.:

a) Iron blast furnaces WP – produce pig iron for further processing in oxygen converters, allowing casting of foundry pig iron – the basic materials necessary for production are sinter, coke, fluxing agents, and hot air, which initiates reduction process; denotations: "a_k" = 1,…,k; k – means the number of iron blast furnaces,
b) Oxygen converters KT – producing liquid steel, which is to be further processed off-furnace – the basic materials necessary for production are pig iron from iron blast furnaces, steel scrap, ferrous alloys, limestone;
denotations: "b_l" = 1,…,l; l – means the number of oxygen converters;
c) Off-furnace processing stations, where steel refining processes take place – in modern steel working plants these are AR – liquid steel argon enrichment, LHF – ladle furnaces, in which almost all off-furnace processes may be carried out, RH – vacuum station for steel vacuum degassing;
denotations: "c_m" = 1,…,m; m – means the number of off-furnace liquid steel processing stations;

d) Continuous steel casting aggregates COS, in which the liquid steel is transformed into cast strands – in modern steel working plants 100% of liquid steel is transformed in this way into cast strands of blooms or slabs; denotations: “d_n” = 1,…,n; n – means the number of continuous steel casting aggregates;
e) Rolling mills W, in which the cast strands are transformed into rolled products (final products); denotations: “e_o” = 1,…,o; o – means the number of hot-rolling technological lines.

3. Identification of logistic systems in analysed technological line

Production scheduling is subordinated to the logistic aspect of production system [1-4, 12-16, 22, 23], as well as to supply and distribution systems. Main logistic systems of researched subject, which is a steel working plant, were isolated and shown in Fig. 2:

1. Supply logistics,
2. Entire steel working plant production logistics,
3. Continuous hot processes production logistics,
4. Market products distribution logistics, and
5. Waste material distribution logistics.

The market product distribution logistics (4) is superior in the entire logistics system. It is because the information from this system (orders for end products) force production planning (scheduling) in the entire steel working plant.

Fig. 2 also shows the waste distribution logistics (5) area. This system is as well complex, due to the massive amounts of waste produced in a steel working plant. Currently the majority of produced waste is completely utilised in modern plants, in particular the slag produced in iron blast furnace and steelmaking processes, which is entirely used in cement plants and for road construction.

The aim of this article is to define conditions needed to build a production system model for a steel working plant, beginning with iron blast furnaces and finishing with end product rolling mills, taking into particular account the most difficult processes, as far as scheduling is concerned – the “hot sections” of the steel working plant. Creation of schedules in this area of production may contribute to optimising the use of devices of the entire technological line, thus lowering the production costs.

The model of such system should contain a description of the devices and the technological processes carried out in these devices, and the flow of materials between the individual devices of the line, and should consider the issues of transportation. It would also include the duration times of individual technological processes and passage times between the devices. The scheduling process should eliminate “machine conflicts,” meaning situations when two consecutive melts from iron blast furnaces or especially converters are to be processed on one device. The model must incorporate the close environment at both the input side, which is raw and production materials supply, and similarly at the output side, which is final product distribution (collecting and grouping of orders).

Building of such model and IT production scheduling systems on its basis should ensure supply deliveries of specified products of particular quality parameters in time.

Looking at the steel working plant from the raw material logistic point of view, it may be stated that the steel working plant is the most complex production system. Beginning with supply logistics (1), where bulk deliveries of raw materials require the need to plan and secure the means of transport and communication routes a few years ahead and sometimes even construction. The problem also concerns other production materials and energy carriers. The medium size steel working plant produces between 2 and 5 million tons of steel, which forces raw materials supply twice the size of the amount of production being carried out.

From logistic and scheduling point of view, the most difficult system is the production system (2). The subsystem of continuous hot production (3) has a special place in this system. There is no possibility of pausing or stopping the subsystem's production. The devices being in use in this subsystem have very differentiated operation times. Some technological line devices, e.g. iron blast furnaces have been in use for several, or even more than 10 years. Other devices in technological line operate for several months, others for several days, and some are able to process several or a dozen or so steel melts. The model of whole production system being built and the schedules to be created on its basis must take into account great amounts of incomparable technological parameters, especially ones concerning duration times of individual processes, as well as the divergent character of the flow of materials. All of these factors cause production scheduling to be a highly difficult problem to solve, so the greatest deal of attention must be paid to solving it, since this may lead to gaining the most benefits by increasing production capacity of the entire system.

Currently, no steel working plant in Poland has IT tools for production scheduling at its disposal. In majority of plants, the processes of collecting and grouping orders for final products, and using them for the preparation of orders for raw materials for production are performed by selected organisation units with extremely limited use of IT techniques. This also applies the preparation of production schedules for individual groups of devices of the technological line, on quarterly, monthly and daily schedule levels.

The problem described in the article is not a recent one, from the elementary sciences point of view; however, never have those tools been used for modelling such complicated objects (structures) from the technological processes point of view, as well as from a logistics perspective.

In order to realise the presented task, it is necessary to identify the real material flows in the object under research. It will be possible to determine relationships between production and transportation devices and separate the environment of the research subject using systems theory. Analysis of the load of individual production and transportation devices in the technological line may be carried out using computer simulation.

4. The program of production scheduling in steel working plant

The task of the production planning (scheduling) system in existing infrastructure is to determine the operation starting and finishing times of each device included in technological line, making the assumption that the measurable operation parameters of those devices will be optimum, or close to optimum. Therefore, the problem of pig iron and steel manufacturing, including continuous casting and technological process course scheduling will mainly come down to determining sequences in which the liquid steel will be cast in continuous casting devices. What the periods should be, and which off-furnace processing devices the melts are to be processed on, finishing with the periods in which the melts are to be made in steelmaking furnaces, and when pig iron casting is to be performed should be determined.

The whole technological processes of the “hot sections” of the steel working plant are subordinated to the optimum continuous operation of casting devices. To enable optimum performance of continuous casting devices, the casting process should be realised in series (sequence) as large as possible, i.e. when the series of steel melts are cast uninterruptedly one after another. The quantity of cast melts in one sequence is dependent mainly on the durability of the construction elements of continuous casting devices, such as trolley ladles, continuous casting moulds, guide rolls, casting tubes, etc.

Casting time for single melt in continuous steel casting devices is dependent on the following:

- Single melt steel weight,
- Cast strand’s cross section, and
- Casting speed.

If the production structure of the steel working plant is determined, the amount of pig iron from one cast and amount of steel from one melt are strictly determined, and have approximately the same weight. The cross sections of cast melts in continuous casting devices may vary, and as a result casting speed and demand for liquid steel may vary as well.

To enable the realisation of a continuous steel casting process in long sequences (series) at optimum parameters of technological devices operation, the liquid steel must be delivered to casting stations with specified parameters and at a precisely determined time. Therefore, the steel melting times in converters, the times of off-furnace processing, and liquid steel transportation times between individual stations must be exactly observed, taking into account the pauses caused by waiting for processing start.

The steel manufacturing system together with the continuous steel casting system are the essential systems in whole technological processes of a steel making plant, and they demand scheduling processes on other subsystems. The optimal solution is the situation when waiting time of steel for processing in all the devices in technological line is equal to zero, i.e. when the liquid steel flow system is expectancy-free.

While scheduling, one should take into account, among others, the technological requirements and realisation times, both contained in receiver's orders, organisational requirements, which result from production technological process operation and steel casting, as well as limitations of production devices.

The action of the manufacturing process and steel casting process scheduling usually includes short periods of time, one day as a rule. Taking into consideration the complexity of the task, the whole cycle of scheduling development may be divided into several stages. Division into four stages seems to be the rational solution of the scheduling process:

Stage one – determination of primary parameters.

The following is to be determined in stage one:

a) The quantity (weight) of steel, which will be cast using continuous casting devices over a period for which the schedule is being elaborated (e.g. one day). The quantity of cast steel is determined based on information about the hourly efficiency of continuous steel casting devices with cross sections of cast billets and casting speed assumed;
b) The grades of cast steel - at the same time the amount of steel of a single grade must be equal to weight of minimum single converter's melt (the amount of steel from one melt or multiple melts "n," where "n" is an integer greater than 1);
c) The series of melts, i.e. the amount of melts of a single grade of steel (or grades which may be cast together in one casting sequence), which are cast one after another in a continuous steel casting device;
d) The amount of sequences during one day for every continuous steel casting device;
e) The order of the casting of an individual series of melts (grades of steel);
f) The types of off-furnace processing; and,
g) Other parameters.

In this stage, the assumptions are taken into account that the individual steel melts will be delivered to continuous steel casting devices with no interference in time according to the determined operation cycles of devices with no limitations, which might occur in resources at disposal, essential for the technological process (resources and devices in entire steel working plant‘s technological line).

Stage two – development of detailed sub-programs.

In the second stage, it is possible to begin developing more detailed sub-programs, after having determined the scope and order of melts, which are to be cast in the continuous steel casting devices. The path for technological operations, which have to be performed, is to be determined for every melt. Starting with pig iron casting from iron blast furnaces and converter heat, through all off-furnace processing stations and steel foundry, the duration of these operations should be taken into account. Individual operations should be marked on a chart – schedule. In this stage, the course of technological operations is determined in relative time, assuming that there are no limits as far as resources, essential for the realisation of those operations, are concerned. Individual sub-programs (schedules) are developed for a series of melts of the same grade of steel, or for grades that might be connected together.

Stage three – development of preliminary schedule.

In this stage, the detailed sub-programs developed in relative time are to be merged together, resulting in the creation of an initial schedule. Individual sub-programs are plotted on the initial schedule, which is created in real time. The initial point for the determination of real time is the instant when steel casting starts in continuous steel casting devices, which is equal to the instant of the finishing of steel casting from the previous schedule (e.g. previous day). This applies to the case when the steel casting process on a continuous steel casting device has not been interrupted, or it may be calculated from the instant when the continuous steel casting device has been started, if it has been disabled previously.

Stage four – checking and machine conflict suppression.

As in the initial schedules, individual technological operations were taken into account only in relative time, and for single melting sequence, with no limitations, which might occur considered, because merging of these schedules might result in machine conflicts. This arises from the fact that the need may occur to process two melts at some of the most loaded devices in the steel production technological line, which is impossible. Therefore, the aim of stage four is to check if the initial schedule developed in stage three contains machine conflicts. This stage is the one in which the optimal algorithm is being developed by eliminating possible machine conflicts.

The production schedule developed in stage four is the basis to introduce the melts and steel casting processes in the determined time scope. The first three stages are developed based on human-computer interaction. The fourth stage requires building a mathematical model and creating the corresponding IT tool based on it.

5. Mathematical model creation assumptions

It is assumed that the model will primarily help in ensuring the continuity of the technological process in the entire steel working plant, thus lowering energy consumption, wear of aiding materials (furnace linings), and increasing the efficiency of whole plant, etc.

The assumptions made while building the mathematical model result from the practical requirements of pig iron and steel production and continuous casting in continuous casting devices systems, which may be presented as follows:

- The sub-programs sequence accepted for individual stages remains constant.
- Only one melt may be processed on a single arbitrary technological device at one instant.
- Only the devices which produce pig iron, i.e. iron blast furnaces, produce steel which is to be processed, i.e. converters, devices of off-furnace processing and continuous casting devices may be taken into account in the mathematical model. Other resources, such as pig iron carriages, liquid steel carriages, ladles or overhead cranes are not included in the model, assuming that they have sufficient efficiency and do not limit the pig iron and liquid steel flow between devices. The model includes the transport times for pig iron and steel between technological devices.
- It is assumed that the whole production of steel passes through all of the technological devices. In the case where steel from a certain melt does not have to be processed on one of the off-furnace processing devices, then the processing time in the model is taken as equal to zero.

The limitations, which are to ensure that the generated schedule will be free of machine conflicts and all the devices will be ready to work, are bound with the model assumptions. The limitations may be presented as follows:

- For two adjacent technological operations of a single melt, the consecutive operation may begin only after the preceding operation is finished.
- For two consecutive melts to be processed on a single device, the processing of the second melt may begin only after the processing of the first melt is finished.
- The passing time between some technological line devices may not be longer than the times determined as maximal, due to the lowering of liquid metal temperature.
- Starting times of consecutive melts at selected technological line devices may not be shorter than the times determined as minimal, so the device would be ready to work.

6. Summary

The aim of this article was to form the production schedule creation rules of the steel working plant. To do this, the identification of the research subject, which is a production system in a steel working plant, was performed in respect to both technological processes being run and devices running the processes. For the scheduling purposes, the logistic systems of the steel working plant have been shown. The problems of production flow for selected sections of steel working plant have been researched in articles cited in this work [6-11]. However, the lack of full information about the production flow into the analysed sections, particularly the lack of full final production system analysis, i.e. production realisation deadlines in those sections, justifies taking up this issue. The further research should define mathematical dependencies between defined conditions and limitations and conduct the identification of all technological line objects. The processing duration times of all devices and pass times between them (including precise transportation time measurements) have to be determined, and simulation research should be carried out using IT tools, e.g. scheduling software SimAl.

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Harmonogramowanie produkcji w hucie surowcowej

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

Huta surowcowa stali jest bardzo skomplikowanym systemem produkcyjnym o ciągłym procesie technologicznym, w trakcie którego począwszy od surowców naturalnych (takich jak rudy żelaza, węgiel, kamień wapienny i inne) są wytwarzane finalne wyroby walcowane. Harmonogramowanie produkcji dla takich systemów technologicznych jest zaliczane do problemów nadzwyczaj trudnych. Dotychczas prowadzone prace badawcze w zakresie harmonogramowania produkcji w zakładach hutniczych ograniczały się do wybranych procesów technologicznych lub co najwyżej niektórych wydziałów [2–8]. Utrzymanie ciągłości pracy wszystkich tzw. wydziałów gorących huty surowcowej wymaga zachowania ścisłych reżimów czasowych, a to oznacza, że należy przygotować harmonogramy od dostaw i przygotowania surowców, poprzez wszystkie wydziały ciągu technologicznego do wykonania produktów finalnych.