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SPECIFICS OF METALLURGICAL INDUSTRY FOR IMPLEMENTATION OF LEAN PRINCIPLES

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The ideal balance between innovating and effective financing is provided by the Lean principles. The basic principle of Lean is to eliminate the wastes and to increase the efficiency of production processes. The objective of this article is to define the basic specifics of metallurgical production, to analyze the classical sources of wastes (Ohno's seven wastes) from the point of view of the identified specifics and to propose the priorities for their elimination in metallurgical production.

Key words: continuous improvement, Lean, Ohno's seven wastes, metallurgy

Posebnosti metalurške industrije za implementaciju Lean principa. Idealnu ravnotežu između inovacije i djelotvornog financiranja osigurava se Lean principima. Osnovni princip Lean-a je kako smanjiti gubitke i kako povećati učinkovitost proizvodnih procesa. Cilj ovog članka je definirati osnovne specifičnosti metalurške proizvodnje kako bi analizirali klasične izvore gubitaka (Ohnovih sedam gubitaka) i to s točke gledišta identificiranih specifičnosti i predložiti prioritete za otklanjanje gubitaka u metalurškoj proizvodnji.

Ključne riječi: kontinuirano poboljšanje, Lean, Ohnovih sedam gubitaka, metalurgija

INTRODUCTION

Today, organizations in all sectors must focus on speed, performance and value for a customer in order to remain competitive. The principles of continuous improvement, which represent an important tool for achieving these goals, include setting a long-term vision, working with the challenges, continuous innovation and searching for sources of problems or tasks being solved [1]. Lean is the philosophy driving the concept of continuous improvement. The Lean principles have enabled many organizations to achieve significant economic benefits through increased quality, better cost management and improved product cycle [2]. The basic principle of Lean is to identify and eliminate wastes. This procedure increases the quality while reducing the production time and costs.

Taiichi Ohno, a former significant manager of Toyota Company and the father of the Toyota Production System has defined the seven classical types of wastes in a production company [3]:

- W1: **Inventory** – all parts, products in process and finished goods that are not being processed at the moment.
- W2: **Transportation** – the movements of products that are not actually required during their processing.
- W3: **Motion** – people or equipment moving more than it is necessary for processing of products.
- W4: **Waiting** – waiting for the next production step.
- W5: **Overproduction** – production in excess of customer requirements.
- W6: **Over processing** – caused by unsuitable tools or product design.
- W7: **Defect** – efforts invested into controlling and elimination of defects.

Later, Womack et al. have defined the eighth source of losses such as manufactured goods or provided services which are not demanded or which do not entirely meet the expectations of customers. Many other authors also added losses caused by failure to use human talent [4]. There are many case studies on the implementation of Lean, but only minimum on its implementation in metallurgical production [5] or there are studies focusing on efficiency increase only in selected parts of metallurgical plant logistic chain [6]. However, it is just metallurgical industry that shows a number of specifics which must be taken into account when trying to apply Lean. The objective of this article is to define the basic specifics of metallurgical production, to analyze the classical sources of wastes (based on assembly types of mass production) from the point of view of the identified specifics, and to suggest the priorities for their elimination in metallurgical production.

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EXPERIMENTAL WORK

In order to meet the desired goal, the authors conducted a survey among the experts involved in management of metallurgical companies. The Delphi method has been selected as a methodological basis used for the realization of this survey. There were two main reasons for this choice:

- The assigned topic, due to its complexity, requires the opinion of people who understand both the technical and the managerial side of affairs.
- The Delphi method does not require the experts to meet in person. It supports creative responses that might have otherwise been hampered because of the presence of others.

A team of twelve experts has been chosen. Seven experts represented the management of metallurgical companies of all levels; three experts represented research university workers, with long-term experience in management of metallurgical companies. The remaining two experts were representatives of consulting firms for increasing the efficiency of metallurgical companies. The experts had received a questionnaire from the facilitator in which they were to formulate the specifics of the metallurgical industry in relation to the seven sources of wastes described above.

The Delphi method was realized in three stages. This was done using Schmidt [7] methodology. From preparing and distributing the questionnaires to the evaluation of the third stage, the survey had taken 5 months.

RESULTS AND DISCUSSION – ANALYSIS

Four specifics of metallurgical industry (S1 - S4) have been identified on the basis of the processed outcomes acquired by the Delphi method. The impact of each specific feature on the classical sources of wastes was analysed (Ohno's seven wastes).

S1: Technological and technical basis of metallurgical processes

Metallurgical industry is, above all, represented by blast-furnace and steel rolling production processes, the technological basis of which consists of physical and chemical processes taking place in technically and technologically sophisticated apparatus equipment. In case of the rolling processes, there are also mechanical and forming processes. In addition, they work with hot or liquid metal which is very difficult to store and any cooling and subsequent heating represent considerable losses of perceivable heat. Metallurgical products are not composed of components; they are made of treated material of certain shape, size, and structure, physical, chemical and other properties that make their added value. The products are manufactured on the basis of technological prescripts. While the metallurgical products are apparently simple, their quantity is enormous. The combinations of grades, shapes, sizes, heat treatments and surface treatments create up to tens of thousands of items of rolled products.

Impact on the individual sources of wastes:

As a result of physical and chemical nature of metallurgical production, the individual processes and their production stages are closely technologically linked. The links are mainly caused by the fact that the processes of technological transformation run, in most cases, continuously at high and entirely specific temperatures. If there are any failures in the production cycle, they can go hand in hand with wastes resulting from material degradation which will significantly outweigh the waste of under-capacity exploitation of equipment (waiting). This fact greatly reduces the possibility of inventory creation in certain stages of production (work with liquid metal does not allow storage). The production technology, however, requires keeping inventory, which has a technological function. Inventory in the ore stockyard serves as a typical example (necessary for homogenization of ores). Thanks to the nature of metallurgical products (the number of finished products is much higher than the number of input materials and raw materials), it is necessary to look for potential elimination of unnecessary transportations and handling operations, especially at the end of the material flow (in assembly types of production it is reversed).

Because metallurgical production takes place in apparatus devices, the workers do not perform manufacturing operations directly, but they have controlling and regulating function. That is why inefficient motions of people or equipment or over processing due to the use of inadequate tools do not pose a threat of direct waste of manufacturing process efficiency. From this perspective, the physical movement of workers is not of fundamental importance, unlike their qualification and experience. A large amount of waiting (defined as waiting for the next production stage) is of technological nature. Cooling of rolled products on cooling beds can serve as an example here. The waiting is also caused by service and maintenance of technically sophisticated production devices. Eventual equipment failures and accidents have very serious character and they can cause very long waiting. Over processing may occur in case the technological prescript is not observed (or it is inefficiently designed).

S2: Material and energy demandingness

Metallurgy is highly demanding sector of industrial production as far as the material and energy consumptions are concerned. The structure of the operating costs is dominated by the costs of raw materials, fuel and energy (up to 80% of total costs), the quality, price and utilization of which are the primary factors of metallurgical production efficiency.

Taking into account the absence of domestic raw material base, many European metallurgical companies depend on the purchase of basic input raw materials from a small number of suppliers located in relatively remote destinations (Asia, South America, Australia). The delivery time of raw materials can vary up to many months.

Impact on the individual sources of wastes:

The metallurgical companies keep relatively high amounts of raw materials, materials, intermediate products and finished products in stock. Apart from technological stock at the ore stockyard, the level of inventories of raw materials is significantly influenced by weather. The winter period is particularly critical as there are delays in deliveries of raw materials and they freeze. Metallurgical companies solve this problem by stocking up in advance, which leads to increased amount of capital being frozen in inventory and increasing cost of maintaining them. Stocks of semi-finished products have negative impact on the company economics as well. In addition to the cost of their maintenance, they are also associated with high costs of consumption of heat energy needed for continuous heating of stored (unnecessarily cooled) semi-finished product.

Due to the large volume of raw materials and long distance transport, the transportation can be a source of waste of metallurgical companies as well. The examples include transportation of iron ore with low iron content, which increases the number of transported trains of wagons.

The area of defects is specific as well. Given that the defects are reversible materials which are used for new production, the wastes due to defects are reduced to energy losses. That is why it is necessary to identify defects early at the beginning of the material flow so as to discontinue production from poor quality material by using additional energy.

S3: Large production batches and volume processed in a single cycle

Metallurgical production has the character of mass and batch production. Mass production can be represented by blast-furnace and sintering manufacturing processes, batch production takes place in the subsequent processes. Batch production is characterized by gathering orders in large batches, which allows maximizing the capacity exploitation of the capital-intensive production facilities.

The production equipment of metallurgical companies is often designed to process relatively large quantities of products within one cycle. However, even if the devices are designed for smaller quantities, constantly increasing diversity of product range and a decreasing number of production orders can lead to problems with their exploitation.

Impact on the individual sources of wastes:

Gathering production orders into batches is naturally associated with higher stock of semi-finished products. In addition to that, the production batches of various processes are created on the basis of different criteria of optimality. A typical example is the discrepancy between the optimal production batch of the steel manufacturing process and the rolling processes. In the steel works, the production orders are accumulated into sequences of continuous casting according to steel grades, but rolling mills gather production orders into a rolling campaign according to the profiles (shapes and dimensions). This conflict is usually solved by creating an inventory of castings between both production processes. On the other hand, reductions of production batches lead to a decline in stock of semi-finished products, but it causes a significant increase of conversion and setup times of equipment (the length in case of metallurgical equipment varies by hours).

Large amount of material processed in one cycle can cause over-production or, on the contrary, low exploitation of equipment. Steel smelting is an example of over-production, when it is not fully covered by production orders, but it is expected to pose no problems to sell the remaining part of steel. A heat treatment furnace not used to its maximum capacity can serve as an example of low exploitation.

From the perspective of defects, large amount of material processed in one cycle is reflected in the risk of a large number of defective products.

S4: High demandingness for organization and operational planning and control

In a single chain, there are processes with different character of the technological process (continuous processes are combined with discrete ones), different duration of production cycles and the amount processed in one cycle. The metallurgical production processes are also influenced by a large number of factors, characterized by considerable variability, stochastic character and close mutual cohesion.

Production is characterized by its complexity and by the existence of variability of its production ways. There are often more technological methods of production of steel, more steel customers (equipment for continuous casting, forging, and foundries), various secondary metallurgic operations, and various treatment operations. Bottlenecks occurring in metallurgical production have the nature of floating capacity bottlenecks [8].

Metallurgical companies are characterized by their large extent given by their great space requirements for each technology and storage of raw materials, semi-finished and finished products. Changes in layout of production equipment, or eventually creation of some storage space would require such extensive investments that they are only very difficult to realize. In addition to that, in many companies the layout of production equipment is irrational, because it was created by gradual additions and modernizations taking place over several decades.

Impact on the individual sources of losses:

The occurrence of stochastic effects (fluctuations in supplies of materials and consumption of semi-finished products, variability in production and handling times, the risk of unplanned events leading to discontinuation of the production cycle), the continuous nature of production processes and long transport distances lead to the creation of buffer stock in front of the key manufacturing devices (if allowed by the technological procedures).

The variability of production routes, the vast character of metallurgical companies and irrational deployment of production equipment lead to unnecessary or excessively long handling operations. Demandingness of organizing and operational planning and control causes organizational waiting (for example because of missing material or unavailable handling equipment), over processing because of failure to keep the technological prescript or due to defects.

RESULTS

The synthesis of results of the analysis of classical sources of wastes in terms of the identified specifics of metallurgical production is presented in Table 1. The significance of the individual sources of wastes is indicated by crosses in the table (three crosses = very important, without cross = completely insignificant). Based on the synthesis of the achieved results, it is possible to determine the priorities for elimination of the classical sources of wastes in metallurgical companies. Priority should be given to inventory, transportation, and waiting. Defects, over processing and overproduction have a lower priority.

Table 1 **Importance of classical sources of wastes for metallurgical companies**

S/W	W1	W2	W3	W4	W5	W6	W7
S1	xxx	xx		xxx		x	x
S2	xxx	xxx					x
S3	xx			xx	x		x
S4	x	x		x		x	x

CONCLUSION

The obtained results confirm the considerable potential for increasing the efficiency of metallurgical companies. However, metallurgical production is so specific that the elimination of these losses can use the familiar tools of Lean only in limited extent, or not at all. 5S technique, kanban, manufacturing cells or SMED can be used as examples. Furthermore, some sources of wastes are given by the current state of technological development of metallurgical processes and equipment [9], and their elimination is not currently possible or would require high investments. The technological inventory and waiting or long conversion and setup times can serve as examples of that.

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