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# LOGISTICS WASTE UTILIZATION SYSTEM IN THE STEEL PLANT

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***Abstract:*** *An important problem associated with the production of steel products is the need to ensure adequate protection of the environment. Throughout the technological foundry formed about 90 types of waste, while a significant number of them belongs to a group of hazardous waste. Resulting in the production system have a steel mill waste utility value to justify the economic and ecological use, not only in the steel sector but also in other sectors of the economy. There is a need to increase activities related to environmental waste management from manufacture of steel, particularly those whose development is one way of storage. The paper presents the concept of reverse logistics in the specific example of a steel mill a full production cycle and the overall costs generated within the waste management system of a full production cycle steel mill.*

***Key words:*** *logistics system, steel plant, waste utilization, waste stream*

## 1. Introduction

Production of steel in the world is in the last 5 years, very variable (for example, in 2009 - 1 238 mln Mg crude steel, 2010 – 1 433, 2011 - 1 537, 2012 - 1 559, 2013 - 1 606 mln Mg) [1]. According to data reported annually in the World Steel Association reports continues to grow production in China (in 2010 – 626,7 mln Mg crude steel, 2013 – 779, mln Mg). Polish steel mill producing for ArcelorMittal also to note the large fluctuations (2006 - 10.0 mln Mg crude steel, 2007 - 10.6, 2008 - 9.7, 2012 – 8,4, 2013 - 8.0 mln Mg). Still, the world needs a lot of steel, and thus created a lot of different wastes. An important problem associated with the production of steel products is the need to ensure adequate protection of the environment. Steel is 100 % recyclable and can be used in new products and applications amounting to significant energy and raw materials savings.

Productive waste material are the undesirable occurrence, hence the tasks of the logistics of the repeated utilisation of metallurgic waste material should be activities pursuing of the minimization of the quantity of nascent waste material, and also to their full utilization by means of the reusing in metallurgical processes, or in the other branches of the economy ( [2]. In addition, it is very essential to keep the suitable proportions among ecological and economic aspects [3]. Over 90 kinds of waste material is generated in the whole technological processes of the steelworks, and mostly there are waste material undesirable for the environment, containing - among other things - oils, heavy metals (Mn, Pb, Cr, Cd, Zn, Cu, Ni, Al), asbestos, phenols, bituminous matters [4]. During the last years, in the metallurgy, the considerable degree of these waste material utilization has been reached - exceeding 90% of their total quantity.

## 2. The logistic approach to the problem of waste material

The operational point of view of the logistic activities in the steel plant should then include the logistics system consists of: supply, production, distribution and the repeated utilization of wastes. While aspects of the logistics of the supply limit themselves to reduce pollution of the environment both on the entry and the exit side of the manufacturing process, this the logistics of the repeated utilization of waste substances contributes to solve ecological problems in the environmental protection [5]. According to the logistics of the repeated utilization of wastes (the logistics of the recirculation), all substances nascent in the production process, which are not purposely manufactured products, are being qualified as, so called, remains. As the repeated utilization of wastes one ought to understand - according to [6] - „...the use of the idea of the logistics with reference to remains, for only to cause economically and the ecologically efficient transfer of remains, with the simultaneous spatially - temporary transformation, inclusive with the change of the quantity and the sort".

One can then conclude (in reference to definition of the logistics) that the logistics of repeated utilization of waste materials is a system, which:

- bases on the integrated idea of planning, management and control of waste materials (solid, liquid and gaseous) flows as well as the related information,
- assures the readiness and the ability of neutralizing or the liquidation of waste-materials according to accepted technical and technological rules, which ought to meet standard and legal regulations concerning environmental protection,
- assures the readiness and the ability of neutralizing or the liquidation of waste-materials according to accepted technical and technological rules, which ought to meet standard and legal regulations concerning environmental protection,
- enables making decisions leading to minimizations of the quantity of waste material accompanying the production, distribution and consumption processes.

One of the major concerns of world steel industry is the disposal of wastes generated at various stages of processing. The global emphasis on stringent legislation for environmental protection has changed the scenario of waste dumping into waste management [7]. Remains - depending on the possibility of reuse or further treatment - are divided on the secondary utilised raw materials (available to the direct reuse) and the other waste material, which can occur in the form of the constant, liquid and gaseous phase. These interdependencies for steel plants are shown in Figure 1.

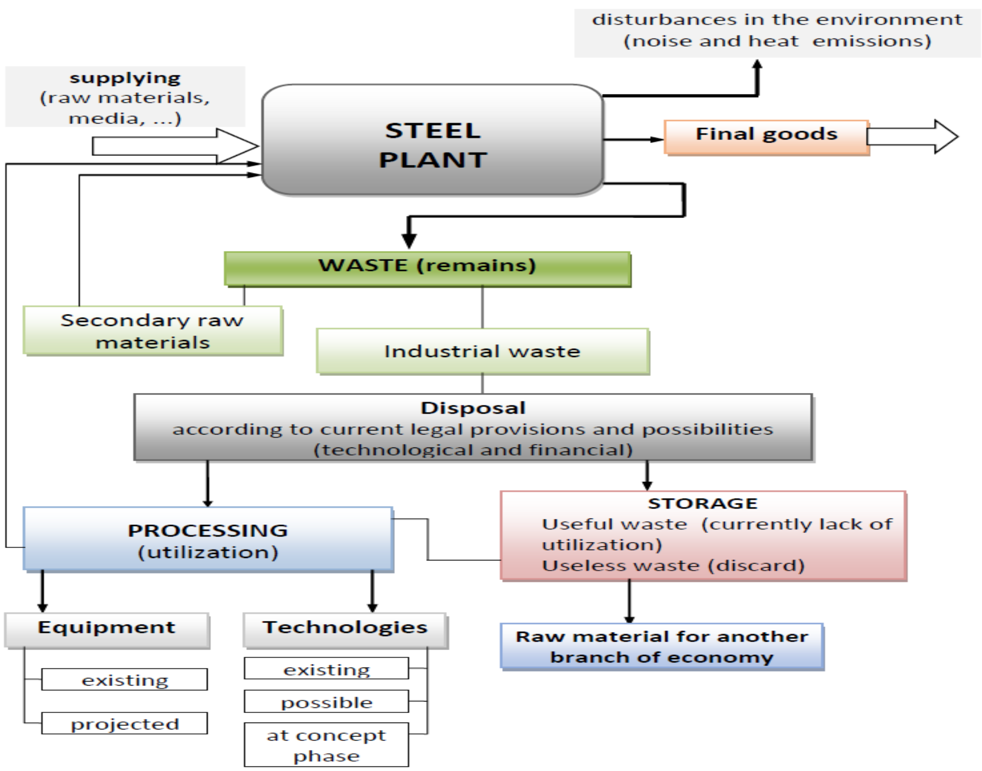


Fig.1. Relationship in the logistic system of the waste disposal

The fundamental definitions of logistics have evolved considerably in recent years. From the point of view of the tasks of logistics it is worthwhile to defer to the definitions contained in The Council Supply Chain Management Professionals (CSCMP) Glossary of Terms, which slightly differs from some European definitions (e.g. ELA). The following description of the objects of logistics and of logistics management demonstrate this quite clearly. According to the European Logistics Association-ELA (2005): *Logistics* – it is the management of processes of goods and/or persons transfer together with activities supporting these processes in systems in which they occur. Systems, in which these processes (of goods and/or persons transfer) appear are both economic systems - whose activity is profitably oriented (industrial enterprises or commercial companies together with the delivery/supply chains) – as well as the non-profitable systems (the public medical service, the public education, municipal systems, environment or surrounding systems).

*Objects of logistics* are physical goods such as raw materials, preliminary products, unfinished and finished goods, packages, parcels, and containers or waste and discarded goods [8]. CSCMP (2010): *Logistics management* is the part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements [9].

## 3. The logistic system of the waste disposal in the metallurgy

Solving the problem of waste management is possible by the metallurgical processing of complex steel mills, as a system of interdependent units-departments, businesses and relations between the steel plant and the environment [10].

The LSWU system (Fig. 2) one can define taking into consideration the controlled working system SR, the master, controlling system (management) SZ, information system SI and $R_{R,Z,I}$ relations, existing the among these systems:

$$LSWU = < SR, SZ, SI, R_{S,Z,I} > \qquad (1)$$

The working system SR (controlled), in addition, ought to take into account the following subsystems:
- SSG system - storage and gathering of waste material,
- ST system - transportation of waste material,
- SU system - utilization (processing) of metallurgic waste material.

The LSWU system one can define taking into consideration the controlled working system SR, the master, controlling system (management) SZ, the information system SI and $R_{R,Z,I}$ relations, existing among these systems:

$$SR = < SSG, ST, SU, R_{SG,T,U} > \qquad (2)$$

The SZ managing (controlling) system takes into account the management systems of: transport ($S_{ZT}$), storage ($S_{ZS}$), production ($S_{ZP}$), distribution ($S_{ZD}$), marketing ($S_{ZM}$), and the system of costs ($S_K$), so then:

$$SZ = < S_{ZT}, S_{ZS}, S_{ZP}, S_{ZD}, S_{ZM}, S_K, R_Z > \qquad (3)$$

whereas, $R_Z$ represents the relation among above mentioned systems.

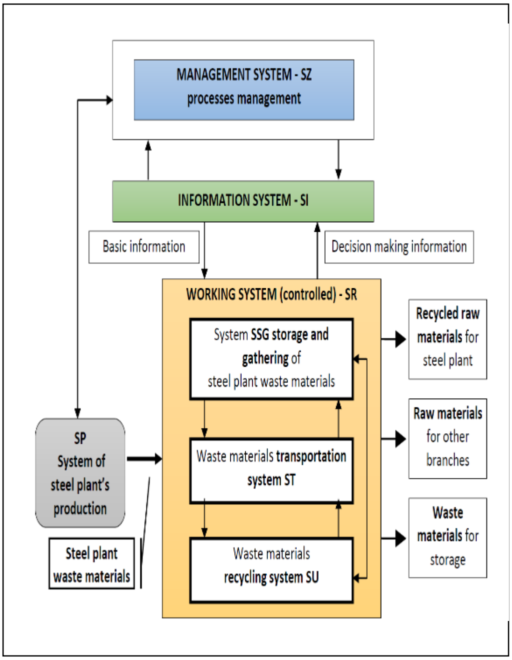


Fig. 2. Logistics system LSWU chart

Waste material entering the LSWU system from the production system and other subsystems, are the input data.
The output data from the LSWU system are [11]:
- secondary raw materials, directly available for reuse in steel plant,
- raw materials useful for the other branches of economy (after previous processing in the steel
- plant or by specialised companies, on a base of an *„outsourcing" contract*),
- selectively gathered and stored waste materials, for which up to now, there are not economically well-founded methods of their utilization (e.g. sludge containing iron) or also at present there is lack of the technology of their utilization.

One of the important systems significantly influenced onto the success of the undertaking activity is the data system, and particularly the system of information technology, which ought to take into consideration the legal regulations of the Waste Material Act, and also the local conditionings and recommendations in relation to waste material utilization (*outsourcing* realised by external firms). The system should possess at least the local area network LAN, which should make possible connection between the separate departments of the steel plant as well as with the *outsourcing* companies, carrying out the waste material utilisation. Nowadays, an additional arduousness in proper prognosis of the waste material utilization is the variable quantity of the total steel industrial output and consequently the variable volume of waste material. The computer-processed information structure of the waste utilization system is presented in Fig. 3. Taking into account the need of computer-processed information for purposes of the widely understanding management and the production controlling (MRP, ERP systems) it seems that such a problem is very essential for the proper exploitation of the steel plant. Within the range of waste disposal an open question is the problem of purchasing of the expensive software accessible on the market, or else - the our own software creation.

Should be a deliberate combination of the database on waste identification with the processes of metallurgical production [12]. For the present mill was built a global database on waste, as well as databases for individual departments.

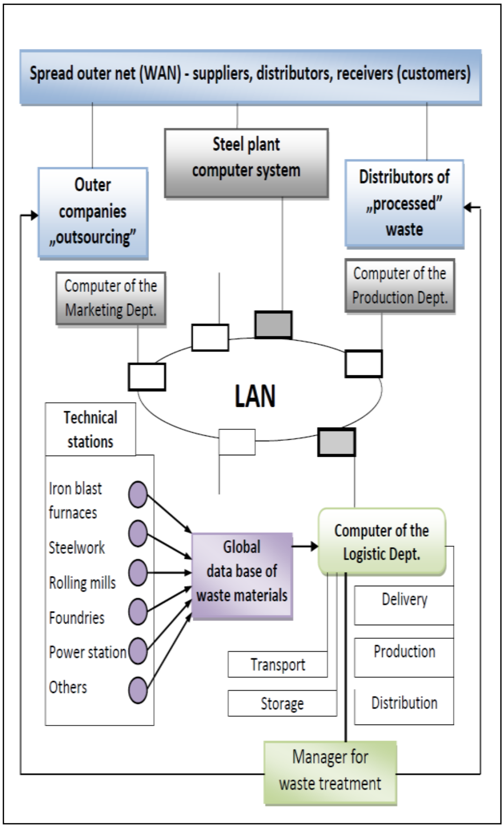


Fig.3. The computer-processed information structure in steel plant

## 4. Waste stream classification

The technologies used for obtaining steel finished products shape the streams of generated waste, both on the industrial and consumptive side [2]. Waste management models implemented at companies are targeted at cost minimization. Cost rationalization constitute the basis of contemporary companies' operations. A company's market success is determined by a proper cost management policy at every stage of task implementation [4]. The set of tasks performed within a manufacturing company can be divided into two groups:

1. Production processes (tasks) directly connected with manufacturing during which raw material input is qualitatively processed to a higher level.

2. Processes (tasks) indirectly connected with manufacturing, primarily aimed at supporting and creating appropriate conditions for the implementation of manufacturing tasks.

Total financial costs incurred in processes of finished product manufacturing and during the implementation of goals supporting the performance of main tasks determine a company's price policy, despite the fact that prices are imposed by the market under current market economy conditions. Expenses incurred within the waste management system are a special area of cost management. Within the organization structure of a steel mill, various kinds and quantities of waste are produced at every stage of raw material input processing. The kind and quantity of generated waste remains in a steel products manufacturing system depends on the technical and technological solutions used.

In the entire structure of a steelworks, approx. ninety various types of remains are generated and 0.6 Mg to 0.8 Mg of waste is produced per each ton of steel products. The volume of generated products is directly proportional to the quantity and quality of finished products. Most waste generated by the steel sector (approx. 90%) can be reused as a full value input product in the same sector or in other branches of industry. Current technical and technological solutions allow for full use of each kind and quantity of waste produced, however, as a result of high financial expenditure, financial efficiency is mostly taken into account in the implementation of pro-ecological activities.

In the waste stream modelling process within the waste management system, the system must be first classified according to established criteria. The first criterion for the division of the waste management system is the place where this waste was produced:

- as a result of the performance of manufacturing tasks,
- as a result of the performance of tasks supporting the manufacturing process.

The largest amount of waste in terms of weight produced within the entire steelworks structure results from manufacturing processes. In this group, three different streams of remains can be distinguished:

1. waste which can be used within the plant,
2. waste managed outside the plant,
3. waste for which management processes are economically inefficient.

The group of waste produced which can be reused in manufacturing processes creates a closed cycle, the so-called feedback for both the waste flow and the capital.

The group of waste managed outside the plant can be divided into two subgroups:

- used as a full value input product in other organizational units,
- processed to minimize harmful environmental impact.

Directions of capital flow in the aforementioned subgroups are different. For waste produced within a steelworks and used in another plant, an open stream is created and the waste is treated like a product at the output. The capital flow for this stream is consistent with the direction typical of a traditional logistics channel - from the recipient to the sender. If an entity whose task consists in the minimization of destructive environmental impact is the recipient of the waste produced, the plant in which this waste was generated covers all costs connected with these actions. Thus, the capital flow is consistent with the direction of the product flow - i.e. from the recipient to the sender.

Waste which is not subjected to the recycling process because the costs of ecological actions are economically inefficient belongs to the third group. Storage is the method of its management and all costs are covered by the steelworks. The capital flow is consistent with the direction of the waste flow - from the recipient to the sender.

Waste streams which contribute to an increase in the plant’s total costs should be minimized on a regular basis and controlled for ongoing verification of deviations between the assumed (planned) costs and the actual costs. Knowledge of waste flow directions and of the capital connected with them allows for preparation of a strategic action plan in the waste management system. Figure 4 presents flow directions for generated waste and capital flows connected with them. The classification of steelworks waste stream makes it possible to assign the arising costs to specific objects or appropriate waste management processes in the target costs accounts within the waste management system. Figure 4 presents main waste streams both open ones and ones with the so-called feedback. Each stream includes a process of a temporary waste flow stoppage in the so-called warehouse buffers. The

storage of remains produced at the facility under analysis is caused by:
- keeping waste on a temporary basis to collect an appropriate amount which is economically useful for processing or transporting,
- waiting until the waste achieves required properties, e.g. the level of cooling,
- a temporary flow stoppage to perform relevant processes adapted to the kind of waste, i.e. separation, segregation, purification or mixing.

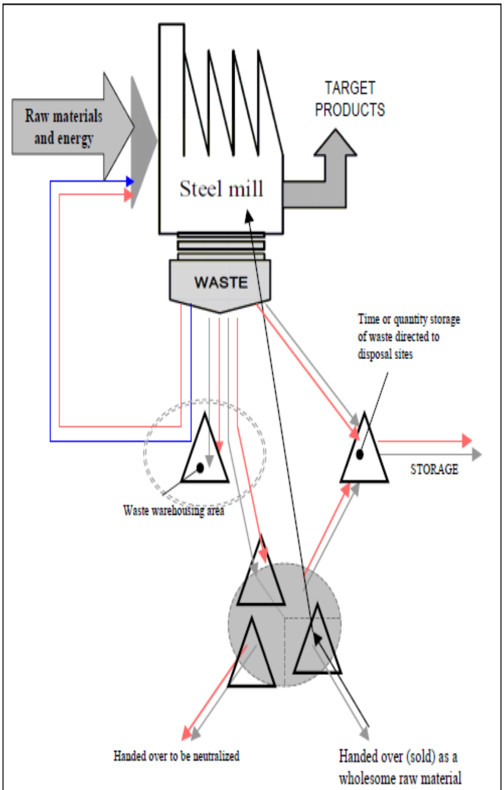


Fig.4. Scheme of main waste streams

Waste warehousing processes take place at designated places of the waste management system infrastructure. Attempts are made at reducing the stoppage time and the length of the transport route [13]. The ultimate account of financial expenditure during implementation of pro-ecological tasks in the company under analysis has several variants. The model of costs directly and indirectly connected with the implementation of waste management tasks depends on:
- the type of stream (open, closed),
- the type of waste (which can be used as a full value recyclable material characterized by market demand, which makes it possible to treat waste as a full-value market product - Fig. 4),
- conditions and duration of warehousing processes.

The modelling of capital flow streams can be performed on an *ex post* or *ex ante* basis. The processes of forecasting financial expenditure in the budget preparation result from experience and conclusions from *ex post* data. All costs arising from the implementation of manufacturing and supporting tasks have a direct influence on the market price of the manufactured product [14]. Actions implemented within the waste management system affect the increase in the product price, however, these are not tasks which influence the product value, both for the manufacturer and the recipient. Waste management processes result from environmental awareness and responsibility. Minimization of the volume of the waste produced in the manufacturing processes and maximization of their subsequent use within the plant where they were generated belongs to cheaper solutions. Only substances containing iron particles (Fe) are subject to subsequent processing at the plant. Substances with another physicochemical composition, due to the lack of technological possibilities, are sent to appropriate organizational units which ensure readiness for and capability of efficient management of the generated waste in conformity with the adopted environmental standards and principles.

The desired effect of coordination of waste management system components at each organizational and functional level consists in developing a comprehensive waste management system fully using all waste generated as far as its quantity and type are concerned. The application of logistics practices and solutions which have been used up to date in the area of eco-logistics [9] for optimization of waste flow tasks influences the reduction in the destructive environmental impact of waste.

**5. The costs of the waste flow stream in a raw steel mill**

The manufacture of final steel products can take place in two different types of steel mills. Namely, in integrated steel mills, where steel is being produced from a raw material like iron ore and in steel mills where the manufacturing of steel products starts with scrap and/or semi-finished steel products penetration [15]. Raw steel mill can be used alternatively with integrated steel mill. In this kind of mill the technological process commences with the production of pig iron and slag constitutes the greatest portion of generated waste. In the whole production process the amount of generated slag fluctuates from 0.5 to 0.8 for each tonne of final product. These numbers depend on the quality of steel produced, in the sense that the higher the quality of steel produced, the more slag is obtained. In integrated steel mills the part of iron slag with the highest content of Fe is reused in blast furnace processes. In the full production cycle steel mill that we use as an example in this article, the amount of slag reused within the company makes up 383 306 Mg/year. Table 1 presents the amount of generated waste, specifying waste streams recycled within the company, waste temporary stored and waste handed over to external recipients in order to be utilized, neutralized or stored. The waste which has the greatest impact on costs and profits value has been included in detail. The data presented below covers one year of manufacture in the analyzed steel mill, where the mean annual production of steel goods approximates 200 000 Mg/year.

Four main processes can be discerned within the logistics system of waste management in the analyzed steel mill:

- recovery,
- warehousing,
- handing over to external recipients,
- storing.

The mass of waste recovered within the company equals 915 727 Mg/year and 42% of that mass consists of slag. Warehousing in the analyzed steel mill is a separate process of temporary retention of flow streams which effect from:

- waiting to accrue a suitable amount of waste which would be then economically and technologically efficient to recover within the company,
- waiting for further flow stages in logistics chain.

The next stages of warehoused waste flow are recovery and handing over to an external recipient in order for it to be neutralized or utilized. According to the Waste Management Act, the duration of warehousing cannot be longer than 3 years and cannot precede the processes of storing.

Table 1. Waste flow streams on the example of a steel mill

| Type of waste | Amount generated | Amount recycled | Amount warehoused | Amount handed over as a product | Amount handed over to be neutralized | Amount stored on-site |
|---|---|---|---|---|---|---|
| | [Mg/year] | [Mg/year] | [Mg/year] | [Mg/year] | [Mg/year] | [Mg/year] |
| **General amount of waste processed** | **1 672 456** | **915 727** | **220 602** | **206 229** | **536 235** | **106 351** |
| Slag as by-product of smelting (blast furnace slag, iron slag) | 746 136 | 383 306 | 219 443 | 119 030 | | 24 357 |
| Sludge and precipitate as by-products of gas treatment | 44 946 | 15 986 | | | | 28 959 |
| Melting loss | | 15 098 | | 26 708 | | |
| Mill scale | | 14 543 | | | | 6 |
| Sulphur from gas treatment | | | 1 159 | | | |
| Carbon flue dust | | | | 23 500 | | |
| Furnace lining and heat - resistant materials from metallurgical processes | | | | 767 | | |
| Solid waste from waste gas treatment | | | | 8 995 | | |
| Particles and dust of iron and its alloys | | | | | | 14 |
| Waste classified as group 20 (solid communal waste) | 1 752 | | | | | |

Handing waste over to external recipients is preceded by time-phased and/or quantity warehousing. The waste for which there is a seasonal demand is directed for time-phased warehousing. Slag is a good example of this kind of seasonal product as it is mostly used for construction works during spring, summer and autumn months. In the analysed steel mill the warehousing processes generate costs as a result of waste management system aims. Costs generated by warehousing processes consist of: waste collection costs, handling operations costs, costs of premises, space and equipment in which waste is being stored, costs of securing the waste from undesirable impact of external factors and additional costs. Additional costs cover all expenses, not mentioned above, that a company would have to bear in order to realize the processes of warehousing. Handing over the waste to external recipients means transferring waste management responsibilities and obligations onto another organizational unit. It is important to fulfill all the organizational and legal formalities as well as obtain all the necessary permissions in the process of transferring the waste. In the analysed company, the processes of transferring the waste can be divided into two categories: those that bring profits and those that generate expenses. The first group consists of waste generating a certain profit, like metallurgical residues originating from production as well as ancillary processes, that are used as entry raw material in another company. This kind of waste as a result of business transaction is treated as a wholesome product, for which there is a certain demand on the market. Companies purchasing materials that are classified as waste in another company generate an added value for that company. The second group of waste generates costs as a result of expenses that a steel mill bears for transport and transformation processes. This group consists of waste undergoing the processes of neutralization (waste containing hazardous substances) and a part of the waste flow stream that is directed to be stored at collective landfills. Logistics costs of managing waste that is handed over to external recipients will sometimes be treated in a company's account as an added value for a group of waste that is sold as a wholesome product to another organizational unit and sometimes as a loss for neutralized waste and partly for waste directed to storage facilities. Waste storage is an undesirable process that has a destructive impact on the environment. In the analysed waste management system there are waste streams that are directed to disposal sites. The first stream consists of waste which could be used as a valuable raw material for the iron and steel industry. Currently, the steel mill does not have a suitable technology for its transformation, thus it is stored for further usage in the future.

The storing period exceeds 36 months, therefore the waste undergoes all the storing procedures according to legal regulations. All the residues with high Fe content, like sludge from blast-furnace and iron gas scrubbing, fall into this category. The second group of waste directed to disposal sites consists of residues that cannot be utilized within the steel mill, like plastic, paper or cardboard waste. Both of the streams mentioned above generate expenses for the company.

The first group of waste, which has a potential of being used in the future is directed to disposal sites owned and managed by the steel mill. The process of storing this type of waste is more expensive as it takes place on the legal and organizational premises owned by the company. From a logistics point of view that takes into consideration local legal regulations, this kind of storage constitutes another form of warehousing. The waste from the second group is directed to disposal sites outside of the company. The storage costs for the steel mill in the first case consist of: environmental fee and the costs of building, exploiting, monitoring and managing the disposal site. In the second case, all of the aforementioned expenses are included in one storage fee that is divided proportionally among all the users according to the mass of waste directed to a disposal site. The type of waste stored is also included in the fee. Relative total value of costs generated within the analysed full production cycle steel mill will be described by a following equation:

$$K_C = K_O + K_M + K_P + K_S + K_D \tag{4}$$

where:

$$K_P = \sum_{i=1}^{m} k_{Pz} + \sum_{i=1}^{m} k_{Ps} \tag{5}$$

$$K_S = \sum_{i=1}^{m} k_{Sz} + \sum_{i=1}^{m} k_{Sw} \tag{6}$$

$K_C$ – relative total costs of waste management system,
$K_O$ – intra-company recovery costs,
$K_M$ – warehousing costs,
$K_P$ – joint costs of waste transfer,
$K_S$ – joint costs of waste storage,
$k_{Pz}$ – costs generated in the processes of transferring the waste treated as wholesome product,
$k_{Ps}$ – costs generated in processes of transferring the waste directed for utilization or neutralization,
$k_{Sz}$ – storage costs at external disposal sites,
$k_{Sw}$ – the sum of costs generated in processes of storing within the company.

The equation (4) presents a simplified method of analysing the costs that the steel mill needs to bear for the realization of generated waste management processes. Total costs of waste management system has been divided into five groups for main logistics processes, according to the significance criterion, creating homogenous cost objects, namely: recovery costs, warehousing costs, transfer costs, storage costs and additional costs. By using the aforementioned classification into cost objects, the individual costs of task completion within the total balance sheet of a company can be easily allocated to the waste management costs account in *ex post* terms. *Ex post* costs object statement constitutes the grounds for planning the *ex ante* account, taking into consideration the fixed costs and other variables depending on the quantity of production.

## 6. Conclusion

At present in steel plants about 0,6 Mg to 0,8 Mg of the different kind of waste material form per one Mg of the produced steel and at this point in time approximately 90 % of that waste material amount is being utilised.

The following undertakings are essential to ensure the efficient management of the waste disposal in the metallurgy:

1.Elaboration of the waste material utilization programme to fulfil the formal requirements:

- the programme concerning minimization of waste material forming,
- disposal projects of industrial waste stockpiles (new technologies and users),
- the specification of external receivers (*the outsourcing)*.

2. Marketing activities intensification (receivers finding) for increasing of the degree of waste material disposal or utilization outside the steel plant („the outsourcing").
3. Verification of contracts with waste disposal companies for the improvement of output, storage and disposal of waste material.
4. Implementation of the proper computer system supporting management of processes of the waste material repeated utilization (it is necessary to establish the global database of waste material, on the basis of classification sheets – in accordance with the Waste Material Act).
5. Installation of the technological line for transformation (for example: briquetting) the iron - bearing waste material, i.e. the utilization of a several percent of remaining waste.

The database should serve not only to the identification and registration but also for waste management (logistics, transport, disposal, storage). Growing demands in the area of environmental protection and striving at minimization of production costs make it necessary to optimize processes not only in the field of manufacturing but also as far as waste management is concerned. Strategic cost management in the area of environmental protection will make it possible to select certain streams of waste which can be managed as full-value recyclable materials and treated as an output product in the market. Reducing operating costs of the waste management system of a given entity can be achieved by integrating various economic systems. This integration should take place at the functional and organizational as well as technical and technological levels.

The necessity of ensuring an appropriate level of environmental protection to prevent negative environmental impact of the waste produced is an important problem. The range of steel products currently manufactured in the world is very broad, which contributes the diversity of organizational and technological structures of steel companies. Despite the fact that it is difficult to find steelworks with an identical technological structure, the classification of the waste management system proposed in this article which relies on the object and process criteria can be used in a majority of such plants. Strategic cost management in the area of environmental protection strives for reducing all components of a given object during the entire cycle of its operation. [16] It is necessary to intensify pro-ecological activities connected with waste management from the steel industry, especially from companies whose streams are directed to landfill sites.

In full-scale terms, the steel mill does not have technologies for efficient utilization of e.g. plastic waste. The market economy forces steel mills to optimize all of the costs generated from production and ancillary processes. Creating procedures and taking actions aimed at managing a small part of waste (in relation to the total mass of generated residues) would increase the waste management costs and therefore decrease the competitiveness of the company. Enhancing the ecological efficiency of individual companies without the legal and financial help from the government (or the commonwealth of states) decreases the financial efficiency of a company. The profit and loss account plays a pivotal role in the functioning of companies and taking environmentally friendly actions usually means obeying environmental protection regulations as stated by the statutory law.

**References**

[1] *World Steel in Figures*. World Steel Associatiotion: www.worldsteel.org (2 November 2014).
[2] Al-Otaibi S.: Recycling stell mill scale as fine aggregate in cement mortars. *European Journal of Scientific Research,* Vol.24 No.3 (2008), pp.332-338.
[3] Szołtysek J.: *Logistyka zwrotna. Reverse logistics*. Poznan, ILiM 2009.
[4] Fierens S.: Impact of Iron and Steel Industry and Waste Incinerators on Human Exposure to Dioxins, PCBs, and Heavy Metals: Results of a Cross-Sectional Study in Belgium. *Journal of Toxicology and Environmental Health*, Part A, Vol. 70, (2007) 3 & 4, pp.222 – 226.
[5] Korzeń Z.: *Ekologistyka*. Poznan, ILiM 2001.
[6] Pfohl H-CH. *Logistiksysteme.* Springer – Verlag Berlin Heidelberg 1996.
[7] Gajdzik B.: Environmental aspects, strategies and waste logistic system based on the example of metallurgical company. *Metalurgija, Vol.* 48 No.1 (2009), pp. 63-67.
[8] Gudehus T., Kotzab H.: *Comprehensive Logistics,* Springer-Verlag, Berlin Heidelberg, 2009.
[9] Taylor G.D.: *Logistics Engineering Handbook,* CRC Press Taylor&Francis Group, Boca Raton, 2008.
[10] Michlowicz E.: The Project of Logistics Waste Utilization System in the Steel Metallurgical Plant. *Polish Journal of Environmental Studies,* Vol.16, No. 3B (2007), pp.347-350.
[11] Jodłowski W.**,** Michlowicz E., Zwolińska B.: Influence of Recycling on Changes in Structures of Production Systems. *Polish Journal of Environmental Studies*, Vol.16, No. 3B (2007), pp.200-203.
[12] Lenort R., Samolejová A.: Analysis and Identification of Floating Capacity Bottlenecks in Metallurgical Production. *METALURGIJA*, Vol. 46, No. 1 (2007), pp. 61-66.
[13] Voss S., Pahl J., Schwarze S.: *Logistik Management.* Physica-Verlag und Springer Verlag, Heidelberg 2009.
[14] Samolejová A., Feliks J., Lenort R., Besta P.: A Hybrid Decision Support System for Iron Ore Supply. *METALURGIJA,* Vol. 51, No. 1(2012), pp. 91-93.
[15] Gajdzik B., Michlowicz E., Zwolińska B., Kisiel P.: Model of truly closed circuit of waste stream flow in metallurgical enterprise. *METALURGIJA, Vol.*53, No. 2 (2014), pp. 257-260.
[16] Michlowicz E., Zwolińska B.: Capital stream flow modeling in a steel mill waste management system. *Conference proceedings* 21th International Conference on Metallurgy and Materials METAL 2012 Brno, TANGER Ltd., s.1642-1648.