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PIPE PRODUCTION COST MANAGEMENT MODEL BASED ON GRAPH THEORY

The pipe production process is a complex dynamical system with a significant number of production operations and interconnected cost localization centres.

Purpose. To develop a mathematical model of the process of handling analytical information of a pipe enterprise using graph theory for the needs of cost management at each production stage.

Methodology. Technological flow charts of the production job, where the list of mandatory activities and routing of the operating process are indicated, were used to organize cost accounting by operational centres of their localization with the help of computer modelling elements, namely the graph theory. The work used a complex of research methods, including analysis and scientific synthesis of scientific and technical information; theoretical studies; methods of mathematical and computer modelling, engineering developments.

Findings. The cost accounting process is represented by a directed hypergraph. Each production operation is associated with a graph vertex. Each vertex is assigned to a series of interrelated marks: type of technological operation; weight factor; the value of direct costs for the operation; the value of indirect costs for the operation; the expense factor. The initial state of the hypergraph is specified by means of its initial marking, which corresponds to the set cipher of the batch of pipes and its weight. Further execution of the marked hypergraph is performed by running the allowed vertices. Marking of the graph ends if all the information from the technological flow charts of pipe products has been used.

Originality. A model of cost management by operational centres is proposed which will allow dividing the prime cost of pipes which differ according to the production technology. It is recommended to rank pipe products within each technologically similar group for an economically feasible allocation of costs between batches of pipes. The proposed process model of processing analytical information of the pipe enterprise using graph theory will allow providing data governance as for the prime cost of each individual batch of pipe products, will contribute to the improvement in the order generation procedure taking into account the acquired information, and will allow making the appropriate adjustments when making management decisions.

Practical value. Calculation of expenses for production operations allows one to identify the most cost-intensive of them. Relying on the results of the calculation, the enterprise management has the opportunity to manage costs at any stage of the production process. Moreover, the model allows determining the amount of consumed metal for each production operation, which is relevant for pipe enterprises. It is appropriate to focus further scientific developments in this direction on the possibility of managing non-manufacturing cost with the help of mathematical models in economics to optimize the supply and sales activities of the enterprise.

Keywords: *pipe products, cost centre, localization of costs, prime cost, hypergraph, model*

Introduction. In modern economic conditions, mining and metallurgical enterprises face the urgent issue of adjusting to the market environment, assessing their strengths and weaknesses for competitive practices and effective operation. Therefore, an important task is to determine further actions taking into account competitive advantages within a certain strategy.

The competitive position of enterprises of the mining and metallurgical complex is formed, first of all, by factors of operating activity. Risk-based management in this field is associated with financial and commercial risks. The majority of management decisions regarding the production program, prices making and promoting products in the market are made on the basis of information on production prime cost.

The convergence of the development of production enterprises is characterized by the use of the integrated functional and resource-based approach. Therefore, the problem of efficient application of approaches to the management of the enterprise in general and specifically to expenses is becoming particularly relevant. The choice of the order of localization, calculation and distribution of production costs is an important management decision which is adopted on the basis of the appropriate cost accounting model.

Literature review. Management of a business entity is closely related to planning. Enterprise resources are always limited; as a consequence, their creation, distribution, and application can be managed through the formation of detailed plans [1]. Under present-day business conditions, such a management function as planning should ensure the manufacture of competitive products with optimum utilization of the available resources (material, financial, labour ones), i. e., guarantee further flexible development of the enterprise. At the same time, financial planning is the basis for cost management, control over business activities, material flows, financial arrangements with contracting parties [2].

Due to a significant number of risks and uncertainties, business entities are forced to adapt to changing conditions. It is expedient to switch from strategic planning to the iterative approach, according to which plans are adjusted once updated data is available. Furthermore, there are good reasons to proceed from complex to diversified planning, which will increase responsibility for decisions made at each management level [3].

The study of risk maps of the mining and metallurgical enterprises showed that the most significant risks in this field are financial ones: price risk and risks associated with production and logistics which are considered to be potential additional costs and commercial risks: the risk of losing target markets and the risk of rising prices for raw materials and transport services [4]. Taking into account the technological specificity of metallurgical enterprises, it is of immediate interest to ensure the fulfilment of requirements for the functionality of the production management system [5].

Mining and metallurgical production is multi-stage; therefore, the most effective method for calculating the production prime cost is the process method of cost accounting [6, 7]. The possibility of calculating costs for each process stage (phase, stage, production operation) will allow one to adjust the production schedule and make management decisions depending on the current situation at the enterprise (in the industry, the country).

Factors of operating activities significantly affect the integrated enterprise value, which is formed through: analysis of prices within a certain range, product portfolio assessment, use of digital marketing tools and selection of a competitive strategy [8]. The dependence of the result of market coverage on the cost pattern [9] also indicates the relevance of the issue of cost management at the level of an individual economic entity.

Unsolved aspects of the problem. A robust analysis of the organizational structure and composition of production costs of the pipe enterprise showed that the procedure for the formation of operational centres of cost localization requires detailing and the application of the iterative approach.

A growing number of experts are urging the necessity to develop methods of adaptive planning of activities with the use of modern apparatus of mathematical modelling in economics and information technologies. Computer modelling is a rather powerful means of studying the behaviour of complex dynamic systems and is successfully used to solve problems of operational and strategic management. But the issue of modelling the production process of pipe enterprises taking into account its technological specifics is underinvestigated.

The purpose of the article is the formalization of the process of calculating the costs of the processing stage at a pipe enterprise using mathematical modelling in economics and information technologies.

Methods. For material-intensive and technologically-difficult production operations, the key factors are the rational use of available resources, ensuring the highest possible benefit from them and the ability to manage costs by places of their origin and responsibility centres [10].

The appropriate allocation of costs to the relevant costing objects is an objective necessity of manufacturing enterprises. It is possible to characterize costs based on their belonging to a certain article, place of origin, as well as to determine the classification criterion of costs, and calculate the impact of their changes on the prime cost of the costing object with the help of OLAP technologies [11].

The object of the research is seamless pipes made of corrosion-resistant steels of austenitic, ferritic and austenitic-ferritic classes and nickel-based alloys. The production process is carried out in two workshops: the pipe pressing workshop (PPW) – manufacturing hot-deformed pipes and tube stock for further cold rolling, and the pipe drawing workshop (PDW) – manufacturing cold-deformed pipes. To manufacture cold-formed pipes with augmented physical and mechanical properties, cold rolling and drawing are used. The process of cold (periodic) rolling ensures high precision of pipes, high cleanliness of internal and external surfaces, insignificant specific loss of metal, etc. [12].

For the enterprise, the issue is relevant of allocation of costs for redistribution, streamlining of accounting for consumption and loss of metal designating them to the appropriate types of products.

The researched enterprise features a combination of flow and batch production scheduling. The flow production involves a complex of main and auxiliary equipment, and hoisting-and-conveying machinery, which consistently participates in processing and displacing pipe workpieces. The PDW flow production includes furnaces, cranes, cold pilger mills and rolling mills themselves, devices for cooling, cutting, straightening, pickling, and stamping of metal. With batch production scheduling applied, products (semi-finished products) are manufactured in batches. A batch is a group of structurally and technologically identical work objects which are launched and transferred to production simultaneously and are processed sequentially at each operation. The size of the batch significantly influences the specific changeover time, the duration of the production cycle and the performance of the workshop and the enterprise as a whole. At the enterprise under consideration, the batch is a set of pipes. Each set is unique in terms of quantity, length and weight of products (with consideration to steel grade, size, and itinerary). The sequence of production of a certain set of pipes is displayed in the package card, which records all the operations which are performed from the moment of registration to the shipment to the customer.

The process of manufacturing pipe products consists of a certain sequence of production operations, whose prime cost can be calculated both individually and according to the corresponding blocks (if several operations are performed using the same equipment or by workers of the same occupation).

All operations of the pipeline enterprise are classified into main and auxiliary ones. The main ones are operations which increase the degree of completion of work-in-progress inventory (accounting for the follow-up of metal for such operations is expected). Auxiliary operations are those of an auxiliary nature which are not directly related to an individual set of pipes. The main operations are divided into technological and non-technological. Technological ones are the main operations according to which the follow-up of metal occurs (processing is performed) during the accounting month. Non-technological ones are the main operations under which there is no follow-up of metal.

In accordance with the organizational structure of the enterprise and the current technology, production costs are accumulated either by structural units of the enterprise (workshop, division), or by individual types of products (technological groups). Accordingly, the place of the origin of production costs is an organizational reflection of the place of their formation and accounting.

Taking into account the complexity of the technology, the cyclicality and continuity of the production of metal products, the organization of accounting by places of cost origin (PCO) with reference to the main and auxiliary, technological and non-technological operations is being used increasingly. The general principle of cost accounting for a pipe enterprise by operating centres is to obtain the amount of conversion costs for each production operation and allocate it between batches of pipes which have undergone processing on the appropriate equipment.

To allocate conversion costs, it is proposed to apply the ranking of pipe products within each technologically similar group for an economically feasible allocation of costs between batches of pipes, which is possible under the conditions of implementation of cost accounting by operational centres of their localization.

In order to determine the prime cost of a certain batch of pipe products in terms of conversion costs, we suggest dividing all operations that may take place during the production process into the places of cost origin (PCO) of the first and second levels [13]. The first-level PCOs consist of pipe preparation operations; operations of rolling and sink drawing; heat treatments; pickling operations; technical control and finishing operations. Each of the above groups of operations includes second-level PCOs. Thus, pipe preparation operations involve cutting, facing, boring, and turning. Rolling and drawing operations include pipe cold rolling, roller cold rolling, and sink drawing. Heat treatment, accordingly, can be carried out in a gas furnace, in an electric furnace, or by bright annealing. Pickling operations are as follows: copper plating, passivation, degreasing, and descaling. Technical control involves measurement, inspection, ultrasonic testing. The final stage is presented by finishing operations, namely: straightening, sandblasting, shot peening, and grinding. The second-level PCO listed are those technological operations whose cost is the prime cost of a certain batch of pipes.

Step-by-step cost allocation will be carried out in the following sequence [13]:

1. Accumulation of direct costs within the limits of the PCO of the first level.

2. Assigning a second-level weight factor K_i^{PCO} to each PCO, provided that $\sum_{i=1}^{n_{PCO}} K_i^{PCO} = 1$ (within the limits of the corresponding first-level PCOs).

3. Allocation of indirect costs using weighting factors.

4. Calculation of the cost of each operation.

Therefore, using the information from the package card, which includes a sequence of production operations, the name of the equipment on which these operations will be performed, geometric parameters and weight of a certain batch of pipes, we can develop a matrix model of the pipe manufacturing process.

To develop a cost management model, it is necessary to identify the main features of production which affect the organisation of the accounting cycle. When modelling, for each group of the enterprise's business units, a corresponding scheme of features with the required detailing and indexing, which is used for information packages and their delimitation, should be provided.

Analysing approaches to data structuring and modelling of production and accounting processes, we consider it expedient to use graph theory to reflect the process of accumulating information on the calculation of the prime cost of pipe products.

Graph theory is most effective when solving a number of complex problems in information technologies (the theory of communication and coding, optimization of programs, organisation of complex databases and their visualization, etc.) [14].

Examples of the successful application of graph theory are as follows: the study on physical properties of devices with an existing causal structure [15], achieving synchronization in complex networks [16], software configuration of control systems [17], quantitative assessment of damage in the field of civil engineering [18]. For manufacturing enterprises they are: order planning in flow production systems [19], database management in the field of marketing and distribution [20], research into the state of the internal logistics flow with a division into procurement, production and sales components [21] use of the apparatus of symbolic and weighted oriented graphs to describe the cognitive model of alternative strategic scenarios of safety management of the metallurgical enterprise development [22].

Results. Approbation of the proposed methodology was conducted.

Graphs are the most abstract structure which one is to encounter in computer science. Graphs are used to describe automated design algorithms, in finite state diagrams, when solving flow routing problems, and others. Any system which assumes the availability of discrete states or the presence of nodes and transitions between them can be described by a graph. The connections between the nodes of a graph are called edges. If the nodes of the graph are not numbered, then the edges are undirected. In a graph with numbered nodes, the edges are oriented. Edges can be assigned specific weights or marks. Graphs are displayed on a plane by a set of points and lines connecting them, or vectors. At the same time, edges can be displayed as curved lines, and their length is of no significance. Any topologically connected area bounded by the edges of the graph is considered a graph face.

A graph, as a structure which contains a significant number of connections, has the following properties: each element (node, vertex) can have an arbitrary number of links; each element can be connected with any number of other elements; each link (edge, arc) can feature direction and weight. The nodes of the graph contain information on the elements of the object. The connections between the nodes are given by the edges of the graph. The edges of the graph can have directionality, which is indicated by arrows, then they are called directed; edges without arrows are undirected.

If certain values are associated with the edges of the graph, then the graph and the edges are called weighted. A multigraph is a graph that has parallel (connecting the same vertices) edges [23].

To study the cost accounting process, a directed hypergraph G is constructed, whose structure fully corresponds to the structure of the studied system. At the same time, a marked hypergraph $G = \langle P, E, M_0 \rangle$ is presented by a vertex set $P = \{p_1, p_2, \ldots, p_n\}$ (first-level PCO) and by a set of arcs (connection between operations of the second level) and hyperarcs, $E = \{e_1, e_2, \ldots, e_n\}$ (connection between first-level PCOs). For the animation of the dynamics of the system, the marking of the arcs of the graph is introduced. Let us denote N – the total number of production operations, and Np – the number of first-level PCOs. Since all the operating centres of cost localization are divided into first- and second-level PCOs, each technological operation is associated with the graph vertex $p_i, i = \overline{1, N}$; moreover, several vertices will be combined into one hypervertex $\overline{p}_j, j = \overline{1, Np}$ if the production operations corresponding to them belong to the same PCOs of the first level. Each vertex is associated with several interconnected labels:

- a type of production operation;
- the weight factor;
- the value of direct costs for performing the operation;
- the value of indirect costs for performing the operation;
- cost factor.

The starting vertex will always be an alternative one.

In addition to the vertices which correspond to the second-level PCO and directly describe the production process, we add so-called alternative vertices to the hypergraph, which have only one input arc, if there was a separation at this stage of the pipe manufacturing process, and vertices which have only one output arc, in the case of combining sets.

A straight arc (p_i, p_r) in the graph G exists if the production operation corresponding to the vertex p_r is performed after the operation corresponding to the vertex of the graph p_i. The arcs that enter or leave an alternative vertex are also called alternative. To illustrate the process of manufacturing a batch of pipes, marking of graph arcs is introduced. Each arc will also have its own mark vector μ_r^k:

- a code of the batch of pipes;

- a type of processing (main cycle/repetitive operations) of the batch of pipes;

- the weight of the entire batch, or its part (for some production operations, for example, such as measurement, inspection, control – other label parameters are set based on the weight and type of pipe batch, with consideration to the information from the production card);

- the estimated value of direct costs for performing the operation;

- the estimated value of indirect costs for performing the operation.

Note that the alternative arc, which comes from the starting vertex, will have the values of the input costs as cost marks for the operation. Similarly, the alternate arc, which corresponds to the separation, will have corresponding cost values calculated in proportion to its weight.

The state of the process at any moment in time $k = 0, 1, 2, \dots$ is determined by the current value of the graph marking vector $M_k = (\mu_1^k, \mu_2^k, \dots, \mu_{\check{o}}^k)$. The initial state of the hypergraph is given by its initial marking $M_0 = (\mu_1^0, \mu_2^0, \dots, \mu_m^0)$, which corresponds to the set code of the batch of pipes and its weight. Further hypergraph marking is carried out by running the allowed vertices.

When describing the process by a matrix method, the marked graph is specified by incidence matrices $D^- = \left[d_{ij}^-\right]$, $D^+ = \left[d_{ij}^+\right]$ of dimension $n \times n$. Matrix D^- defines the input function of the graph, while D^+ – the output function. The vertex of a marked graph is considered allowed if a necessary number of markers is placed on each input arc, which is equal to or greater than its multiple: $M_j^k \ge d_{ij}^-$. If there are several allowed vertices, one of the allowed vertices is selected for launch. When selecting, it is necessary to determine the type of input allowed vertices of arcs: whether they are simple arcs (AND-arcs) or alternative ones (OR-arcs). The type of the corresponding arc is determined according to the input matrix D^-. If the arc e_q is an input arc for more than one vertex, i.e. $\sum_{i=1}^{n} d_{ij}^- > 1$, it is a hyperarc. A simple arc e_q is an input one for only one vertex, i.e. $\sum_{i=1}^{n} d_{iq}^- = 1$. Note that hyperarcs will be present in the graph if it is constructed to represent the production of several different batches of pipes. From all the allowed vertices which include the same hyperarc, only one vertex is selected to run. The vertex is selected according to predetermined criteria (first of all, it is the code of the batch of pipes and its weight) depending on the type of vertices. Allowed vertices with simple input arcs are launched in turn according to the arrival time of the solution marker.

After the concurrent selection of the vertex, the launch vector F_k of dimension n is formed. The next marking M_{k+1}, resulting from the launch of the allowed vertex in the marking M_k is determined from the formula: $M_{k+1} = M_k + F_k D$, where D is a resulting state transition matrix: $D = D^+ + D^-$. Therefore, at each step k of the calculations, the vertex launch vector F_k is determined and the next graph marking M_k is assessed. Marking of the graph ends if all the information from the technological flow charts is used. The constructed hypergraph identically represents the entire process of manufacturing a batch of pipes of a certain standard (Fig. 1).

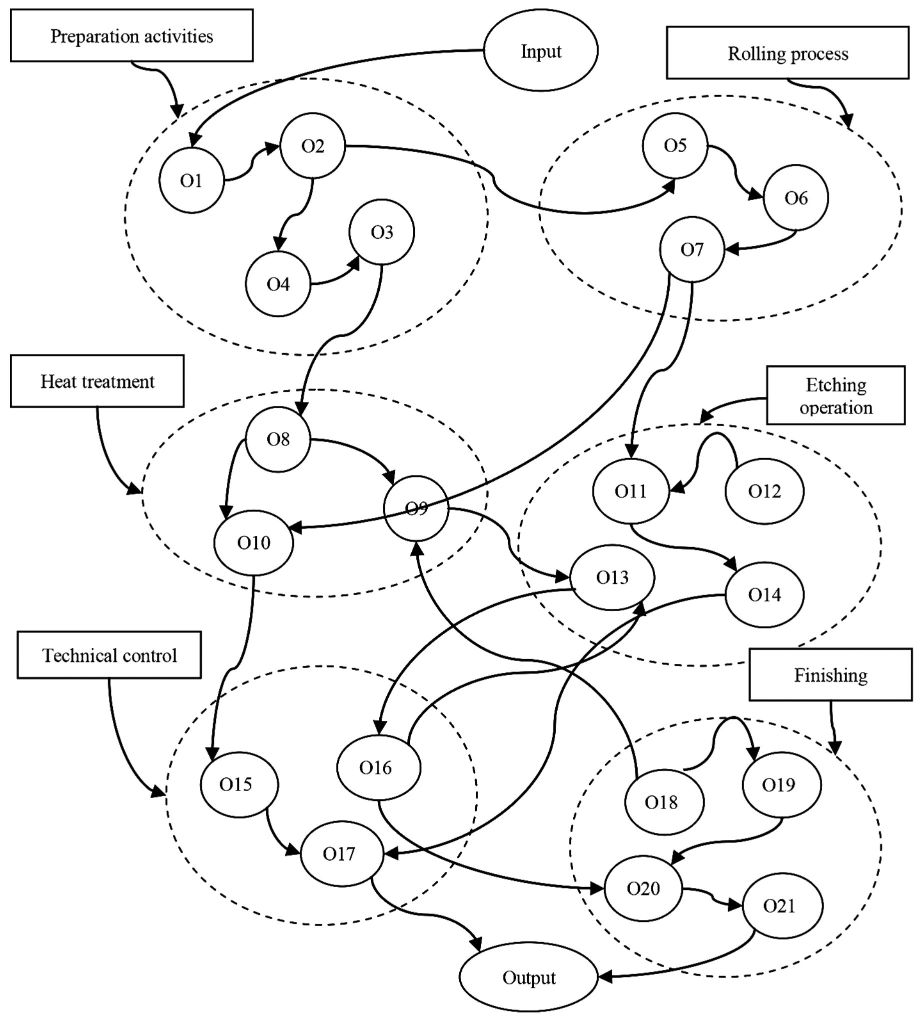

Fig. 1. Cost management model by centres of their localization

Obviously, such a directed hypergraph is connected. At the same time, it contains an open Eulerian chain of simple vertices, since there is one simple starting vertex (the beginning of the manufacturing process of the specified batch), one final vertex (the end of the manufacturing process of the specified batch), while all other simple vertices have an equal number of simple input and output arcs. Thus, in order to determine the cost of a specific batch of pipes, it is necessary, first of all, to build a directed spanning tree for the hypergraph $G = \langle P, E, M_0 \rangle$ with the root at the vertex v_0.

To build a spanning tree, we will use the following algorithm.

Let the graph G be represented using adjacency lists, i.e. N_v is a list of vertices incident to the vertex v, $v_0$is the starting vertex from which the search begins. In the process of depth-first search, the vertices of the graph are assigned numbers (DFS-numbers). At the beginning, the vertices do not have DFS-numbers. Let us begin with the vertex v_0. It is assigned DFS-number DFS(v_0) 1 and the arc with the greatest weight (v_0, w) is selected (as a rule, it will be the only one, since production is just beginning).

The scheme of the developed algorithm is shown in Fig. 2.

During the performance of the algorithm, each vertex of the graph is included in the list Q immediately after receiving the DFS-number and is excluded as soon as a rollback from it is encountered. Inclusion and exclusion always take place from the end of the list, i.e. the list Q is a stack. The algorithm output is four DFS lists, F, T and B: DFS(v) – the DFS-number of the vertex v, $F(v)$ – the name of the vertex from which the vertex v received its DFS-number; T and B are, respectively, lists of oriented "straight" and "reverse" edges of the graph G. If the edge (x, y) is seen from the vertex x as "straight", then an arc (x, y) is listed in T, and if it is "reverse", then this arc is entered in the list B. Thus, let us develop the graph traversal algorithm as follows:

1. DFS(v_0) := 1, $Q(1) := v_0$, $Q(v_0) := 0$, $T := \varnothing$, $B := \varnothing$, $k :=$ 1, $q := 1$ (here k is the last assigned DFS-number, q – end of stack pointer Q, i.e. $Q(q)$ – the name of the terminal vertex of the stack Q).

2. $v := Q(p)$ (v – the simple current vertex).

3. Considering the list N_v, find such a vertex w that the arc (v, w) is not marked, and go to point 4, if there are no such vertices, then go to point 5.

4. If the vertex w has the DFS-number, mark the arc (v, w) as "reverse" and add the arc (v, w) on list B, calculating the value of the cost of the performed operation (at the same time, the cost decreases if the arc (v, w) is alternate and corresponds to the separation). Go to point 3 and continue considering list N_v. Otherwise put $k := k + 1$, DFS(w) := k, $F(w) := v$, the arc should be marked as "straight" and the arc (v, w) is to be added on list T, calculating the value of the cost of the performed operation, $q := q + 1$, $Q(p) := w$ (the vertex w obtained the DFS-number and is put in stack Q). Proceed to point 1.

5. $q := q - 1$ (the vertex is redacted from Q). If $q = 0$ end, else move to point 2.

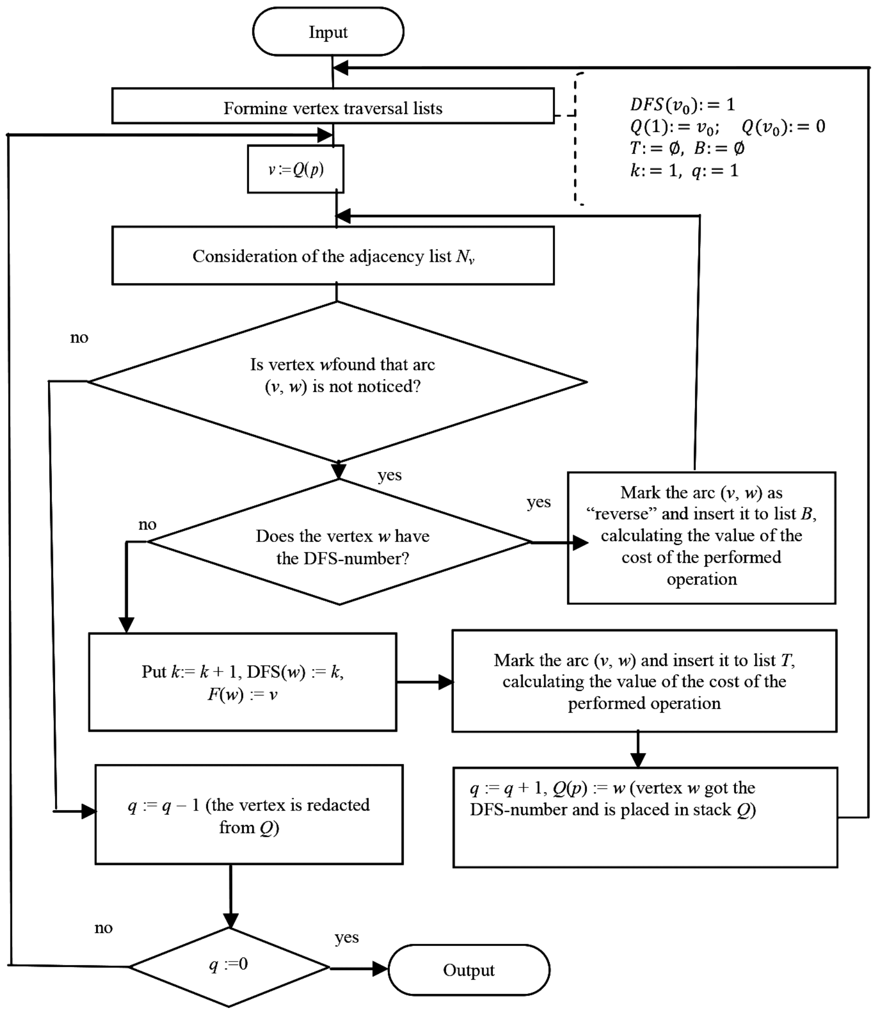

Fig. 2. Cost calculation algorithm:

N_v – a list of vertices; v_0 – the starting vertex from which the search is started; Q – a list which is a stack; T – a list of oriented "straight" edges of the graph; B – a list of directed "reverse" edges of the graph; $F(v)$– the name of the vertex from which the vertex v received its DFS-number; k – the last assigned DFS-number; q – end of stack pointer Q

The traversal algorithm of hypergraph is described.

The correctness of the algorithm is obvious. The described process can be implemented in such a way that the running time of the algorithm is $O(|EG|+|G|)$. Schematically, the proposed algorithm is presented in Fig. 3.

The following statements directly follow from the method of constructing sets T and B.

Statement 1. The arcs of the set T form a directed spanning tree rooted at the vertex v_0.

Statement 2. If the oriented edge (x, y) belongs to the set B, $\mathrm{DFS}(x) > \mathrm{DFS}(y)$.

Thus, in order to calculate the costs for the production of a specific set of pipes, it is sufficient to calculate the sum of the marks of the values of the arcs belonging to the sets T and B, which corresponds to the algorithm for calculating the amount of losses for the production of a certain batch of pipes (Fig. 2).

Conclusions. Therefore, the cost management system involves diversity. Depending on the conditions of production and the nature of accounting, certain types of costs can be attributed to both direct and indirect costs which arise in the process of performing production activities and are calculated in relation to one of the items of direct costs. The choice of the calculation method and allocation of production costs of the enterprise is an important management decision made on the basis of the appropriate cost accounting model.

The proposed model of cost management with the application of graph theory will allow one to consider most conversion costs, which occur during the manufacture of pipe products, as direct ones, to localize costs by the places of their origin, in particular operations, and will provide the possibility of monitoring costs at any stage of the technological process.

The logic of the proposed algorithm provides for a quick and efficient response to the cost accounting procedure of the pipeline enterprise when performing production activities in accordance with the interests of the development of its production and commercial and sales operations. This algorithm enables the management of the pipeline enterprise to make consistent and reasonable management decisions regarding the management of production costs in dynamically changing market conditions.

Calculating the costs of production operations allows one to identify the most expensive of them. Relying on the results of the calculation, the management of the enterprise has the opportunity to manage costs at any stage of the technological process. Moreover, the model makes it possible to determine the amount of metal consumed for each production operation, which is relevant for pipe enterprises.

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Модель управління витратами трубного виробництва з використанням теорії графів

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Процес виготовлення труб являє собою складну динамічну систему зі значною кількістю технологічних операцій і взаємопов'язаних центрів локалізації витрат.

Мета. Побудова математичної моделі процесу обробки аналітичної інформації трубного підприємства з використанням теорії графів для потреб управління витратами на кожній стадії виробничого процесу.

Методика. Технологічні карти виготовлення продукції, де зазначається перелік обов'язкових операцій і маршрутизація виробничого процесу, були використані для організації обліку витрат за операційними центрами їх локалізації за допомогою елементів комп'ютерного моделювання, а саме теорії графів. У роботі використовувався комплекс методів дослідження, що включає аналіз і науковий синтез науково-технічної інформації; теоретичні дослідження; методи математичного й комп'ютерного моделювання, конструкторські розробки.

Результати. Процес розрахунку собівартості представлений орієнтованим гіперграфом. Кожній технологічній операції ставиться у відповідність вершина графа. Кожній вершині ставиться у відповідність кілька взаємопов'язаних міток: вид технологічної операції; ваговий коефіцієнт; вартість прямих витрат на виконання операції; вартість непрямих витрат на виконання операції; фактор витрат. Початковий стан гіперграфа задається за допомогою його початкового маркування, що відповідає встановленому шифру партії труб та її вазі. Подальше виконання маркованого гіперграфа здійснюється за допомогою запусків дозволених вершин. Маркування графу закінчується, якщо при цьому використана вся інформація з технологічних карт трубної продукції.

Наукова новизна. Запропонована модель управління витратами за операційними центрами, що дозволить розділяти собівартість труб, різних за технологією виробництва. Рекомендовано здійснювати ранжирування трубної продукції в межах кожної технологічно подібної групи для економічно обгрунтованого віднесення витрат між партіями труб. Запропонована модель процесу обробки аналітичної інформації трубного підприємства з використанням теорії графів дозволить забезпечити керівництво даними щодо розміру собівартості кожної окремої партії трубної продукції, сприятиме вдосконаленню порядку формування замовлень з урахуванням отриманої інформації та дозволить вносити необхідні корегування під час ухвалення управлінських рішень.

Практична значимість. Розрахунок витрат за технологічними операціями дозволяє виявити найбільш витратні з них. Менеджмент підприємства, спираючись на результати розрахунку, має можливість управляти витратами на будь-якій стадії технологічного процесу. Також модель дозволяє визначити обсяг витраченого металу за кожною технологічною операцією, що є актуальним для трубних підприємств. Подальші наукові розробки у даному напрямі доцільно спрямувати на можливість управління невиробничими витратами за допомогою економіко-математичного моделювання для оптимізації постачальницько-збутової діяльності підприємства.

Ключові слова: *трубна продукція, місця виникнення витрат, локалізація витрат, собівартість, гіперграф, модель*

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