Research of measures to reduce metal processing wastes by analytic hierarchy process

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Abstract. The paper presents the search for the optimal solution of the problem of minimizing metal waste at the production of electronic equipment. The hierarchy analysis method is used to determine the most effective method from different points of view. This method is quite simple, allows the formalization of relations in an arbitrary evaluation scale, and provide a systematic approach to the problem. Alternatives are identified that minimize metal waste in the manufacture of electronic equipment: scales, a waste press, hardware sorting, working with suppliers, optimization of cutting, additive technologies, material incentive system, total accounting and control, advanced training of workers, creation of a new unit. Criteria for comparison of alternatives are the following implementation costs, maintenance costs, overall effectiveness of the event, technical complexity, organizational complexity, the possibility of using standard solutions, the term of obtaining the effect. Based on the results of the calculations, the conclusion about the most effective alternatives based on the proposed criteria is made.

1. Introduction
The increase in the pace of economic development is associated with the transition of industrial enterprises to the new principles of functioning characteristic of the digital economy. These include high flexibility of production processes, individualization of products, the development of key technological competencies and short lead times for new products to market. The use of digital technologies allows to ensure a significant increase in labor productivity, the speed of updating the range of products, reduce the volume of inventories and the duration of production cycles [1].

The development of digital production should be ensured with minimal possible losses and ensuring the continuity of the production cycle. In this case, both direct methods of increasing the efficiency of the production process, and indirect ones, should be used. These include the occurrence of waste during metalworking operations in the manufacture of sheet metal housings or by milling. A significant amount of such waste occurs in small-scale discrete production, with frequently changing orders [2].

At the organization of production of electronic equipment often there are conditions to overcome which it is possible with application of experimental character of production. These include: production with an incomplete set of design documentation or without proven technological routes, production in the presence of only preliminary technological documentation. When performing operations related to metalworking, in the process of such production an offal is inevitably formed - metal waste. Metal waste is chips, parts of equipment or machines, various metal parts, unsuitable for
further use as materials or components. Such metal wastes can be divided into three categories: products that have fallen into disrepair; structures, parts or mechanisms that have worked out the ultimate service life; waste generated during the processing of metal billets (material) [3].

The latter group is characterized by such type of scrap as chips, slag, scale, trim and so on. Distinctive features that characterize the waste metal processing in the production of finished metal products – a high percentage of scrap and its qualitative composition. The second factor is related to the specifics of the outer layer of the workpiece, which has better strength characteristics than the core. The exact volume or cost fraction of waste generated by metal processing depends on the type of manufacturing process. Metal forming (drawing, pressing, forging, stamping) is the most economical way to produce metal products, where the proportion of scrap does not exceed 25%. The highest efficiency is characterized by cold stamping, characterized by a level of waste up to 10%. Common types of waste in the processing of metals under pressure are slag and scale. Waste from mechanical metal treatment is the most common form of scrap metal. These wastes are generated during cutting, turning, milling, drilling, chiselling, grinding or tumbling, as well as the cleaning of equipment components. The next category is waste from heat treatment of metals. It includes three types of secondary product: spent melts of chlorides of barium, magnesium, sodium, potassium and derivatives of these elements; oxide scale; aspiration waste [4].

A distinctive feature of the considered types of waste is its industrial origin in the production of metal products. Such waste accumulates in enterprises and can be used in subsequent metal production. It is necessary to take into account the volume and type of waste arising in the production, to take measures for their effective disposal and reduction.

2. Problem statement

The proportion of metal waste in the mass of purchased for the manufacture of products can be up to 50%, and in some cases more. The purpose of the study is to develop and justify a set of measures to reduce the volume of metal waste. Waste appears in the procurement and mechanical assembly of special-purpose radio electronic equipment: satellite and tropospheric communication stations, navigation and radar equipment. The principles of accounting and waste reduction can be divided into engineering and management. The activities for this are:

- to work with suppliers of materials;
- to optimize metal cutting;
- to use an additive technology;
- to create a new unit;
- to use a hardware scrap sorting;
- to use a material incentive for rationalization ideas to reduce metal waste;
- to use the Kaizen lean manufacturing system;
- to organize own foundry;
- to improve the skills of employees in the field of lean technologies;
- to plan at all stages from the acquisition of metal to the formation of metal waste and its further use or disposal.

These measures are well known, but it is necessary to justify the decision in choosing the most effective for the case of a particular production.

3. Hierarchy analysis method

The method of analyzing hierarchies is a development of the method of expert assessments and allows to represent some existing system in reality as an abstract model [5,6]. This method allows you to evaluate the impact of various components of the system on the entire system and find the priorities of these components [5-10]. The task is to evaluate the highest levels of the hierarchy, based on the interaction of different levels, and not from the direct dependence on the elements at these levels.
Consider the use of the method of analysis of hierarchies to make management decisions to minimize metal waste (figure 1. Flowchart of research).

Figure 1. Flowchart of research.

It is necessary to make a choice from the following set of alternatives according to the approved criteria: $C_1$ – implementation costs, $C_2$ – maintenance costs, $C_3$ – economic efficiency, $C_4$ – technological complexity, $C_5$ – organizational complexity, $C_6$ – the ability to use a standard solution, $C_7$ – timing the results. We use the following notation for the problem: $w_i$ – the coefficient of $C_i$ criteria importance, $i=1...7$; $V(i,j)$ – the coefficient of importance of alternatives $A_j$ when comparing the criterion $C_i$, where $i=1...7$, $j=1...10$; $V(A_j)$ – priority of alternative $j$, where $j=1...10$. As alternatives, consider the following: $A_1$ – scale, $A_2$ – waste baler, $A_3$ – hardware sorting, $A_4$ – working with suppliers, $A_5$ – cutting optimization, $A_6$ – additive technology, $A_7$ – incentive scheme, $A_8$ – total accounting and control, $A_9$ – further training for worker, $A_{10}$ – creation of a new unit (figure 2).

Figure 2. Criteria and alternatives.

Figure 3. Hierarchical model.
The next step is to set up a hierarchical tree. Hierarchical structure can be seen as shown below on figure 3.

In determining the scale of comparison can be used by the Saaty scale. The information received from the experts formed the basis in assessment and determination of these criteria. Table 1 shows a matrix of pairwise comparisons of criteria. The importance of each criterion by fundamental scale of absolute numbers: (1) – equal importance, (2) – weak or slight, (3) – moderate importance, (4) – moderate plus, (5) – strong importance, (6) – strong plus, (7) – very strong or demonstrated importance, (8) – very, very strong, (9) – extreme importance. We introduce an additional column eigenvector to determine the importance of the criteria. The AHP requires evaluating the consistency of the judgments presented by the resulting matrix when implementing pairwise comparisons. Checking the consistency of local priorities is carried out by calculating three characteristics:

- maximum eigenvalue of the matrix ($\lambda_{\text{max}}$);
- consistency index (CI);
- consistency ratio (CR).

The formula to find out the consistency ratio value is as follows:

$$CI = (\lambda_{\text{max}}-n)(n-1)$$  \hspace{1cm} (1)

$$CR = \frac{CI}{P_n}$$  \hspace{1cm} (2)

where $P_n$ is random consistency index, the value of which depends on the dimension of the matrix.

|    | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | Eigen Vector |
|----|------|------|------|------|------|------|------|--------------|
| $C_1$ | 1,00 | 5,00 | 0,20 | 5,00 | 7,00 | 0,14 | 3,00 | 1,47         |
| $C_2$ | 0,20 | 1,00 | 0,20 | 0,33 | 5,00 | 0,14 | 0,14 | 0,37         |
| $C_3$ | 5,00 | 5,00 | 1,00 | 7,00 | 9,00 | 7,00 | 8,00 | 5,08         |
| $C_4$ | 0,20 | 3,00 | 0,14 | 1,00 | 7,00 | 0,14 | 0,11 | 0,51         |
| $C_5$ | 0,14 | 0,20 | 0,11 | 0,14 | 1,00 | 9,00 | 9,00 | 0,62         |
| $C_6$ | 7,00 | 7,00 | 0,14 | 7,00 | 0,11 | 1,00 | 0,14 | 0,96         |
| $C_7$ | 0,33 | 7,00 | 0,13 | 9,00 | 0,11 | 7,00 | 1,00 | 1,11         |

|    | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ |
|----|------|------|------|------|------|------|------|
| $w (i,1)$ | 0,14 | 0,04 | 0,50 | 0,05 | 0,06 | 0,09 | 0,10 |
| $\lambda_{\text{max}}$ | 7,57 |      |      |      |      |      |      |
| $CI$ |      |      |      |      |      | 0,09 |      |
| $CR$ |      |      |      |      |      | 0,06 |      |

Due to result of CR equal to 0,06 then result is consistent because CR value is less than 0.1[6]. If CR is more than 0,1, then a revision is required for matrix of pairwise comparisons of criteria. Next, we make a matrix of paired comparisons of the analyzed alternatives. There is a difference in the calculation process between criteria and alternative options. Alternatives are evaluated for each criterion. Tables 3-9 present the results of calculating the importance coefficients of alternatives for each criterion, and $\lambda_{\text{max}}$, CI and CR are found.
Table 3. Coefficients of importance of alternatives by criterion $C_1$.

| $A_i$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ | $A_8$ | $A_9$ | $A_{10}$ |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| $V(i,1)$ | 0.07 | 0.13 | 0.13 | 0.05 | 0.06 | 0.07 | 0.05 | 0.10 | 0.07 | 0.23 |
| $\lambda_{\text{max}}$ | 10.83 | 0.09 | 0.06 |

Table 4. Coefficients of importance of alternatives by criterion $C_2$.

| $A_i$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ | $A_8$ | $A_9$ | $A_{10}$ |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| $V(i,2)$ | 0.06 | 0.16 | 0.14 | 0.15 | 0.07 | 0.07 | 0.05 | 0.11 | 0.06 | 0.09 |
| $\lambda_{\text{max}}$ | 10.61 | 0.06 | 0.04 |

Table 5. Coefficients of importance of alternatives by criterion $C_3$.

| $A_i$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ | $A_8$ | $A_9$ | $A_{10}$ |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| $V(i,3)$ | 0.10 | 0.02 | 0.08 | 0.02 | 0.16 | 0.05 | 0.03 | 0.04 | 0.20 | 0.05 |
| $\lambda_{\text{max}}$ | 10.78 | 0.08 | 0.05 |

Table 6. Coefficients of importance of alternatives by criterion $C_4$.

| $A_i$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ | $A_8$ | $A_9$ | $A_{10}$ |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| $V(i,4)$ | 0.05 | 0.20 | 0.02 | 0.24 | 0.07 | 0.11 | 0.02 | 0.06 | 0.05 | 0.14 |
| $\lambda_{\text{max}}$ | 10.12 | 0.01 | 0.006 |

Table 7. Coefficients of importance of alternatives by criterion $C_5$.

| $A_i$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ | $A_8$ | $A_9$ | $A_{10}$ |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| $V(i,5)$ | 0.05 | 0.24 | 0.07 | 0.11 | 0.06 | 0.12 | 0.031 | 0.11 | 0.06 | 0.11 |
| $\lambda_{\text{max}}$ | 10.45 | 0.05 | 0.03 |

Table 8. Coefficients of importance of alternatives by criterion $C_6$.

| $A_i$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ | $A_8$ | $A_9$ | $A_{10}$ |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| $V(i,6)$ | 0.21 | 0.19 | 0.06 | 0.16 | 0.06 | 0.04 | 0.04 | 0.11 | 0.06 | 0.04 |
| $\lambda_{\text{max}}$ | 10.98 | 0.1 | 0.06 |

Table 9. Coefficients of importance of alternatives by criterion $C_7$.

| $A_i$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ | $A_8$ | $A_9$ | $A_{10}$ |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| $V(i,7)$ | 0.13 | 0.19 | 0.04 | 0.30 | 0.06 | 0.07 | 0.04 | 0.03 | 0.06 | 0.05 |
| $\lambda_{\text{max}}$ | 10.65 | 0.07 | 0.04 |
Knowing coefficients of importance of criteria and coefficients of importance of alternatives we find priority of alternative. The calculation of the effectiveness of each of the alternatives according to the following formula:

\[ V(A_j) = w_1 V(1,j) + w_2 V(2,j) + w_3 V(3,j) + w_4 V(4,j) + w_5 V(5,j) + w_6 V(6,j) + w_7 V(7,j) \]  

(3)

Based on table 10 shows that highest value of \( V(A_j) \) become main to determine the best of alternative while lowest value represents unimportant alternative.

Table 10. Priority of the alternatives.

| \( A_j \) | \( A_1 \) | \( A_2 \) | \( A_3 \) | \( A_4 \) | \( A_5 \) | \( A_6 \) | \( A_7 \) | \( A_8 \) | \( A_9 \) | \( A_{10} \) |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| \( V(A_j) \) | 0.13  | 0.18  | 0.07  | 0.19  | 0.14  | 0.11  | 0.04  | 0.09  | 0.15  | 0.19  |

4. Conclusions

In this paper, we study on how to evaluate the future effectives of a solution to reduce metal waste at the production of electronic equipment. Based on the calculation results, the best three equivalent alternatives were obtained: using a waste baler, working with suppliers and creation of a new unit. It is also worth noting that high priority was given not only to measures that were obvious in terms of the speed of obtaining the economic effect, but also quite costly, among which the creation of a new unit or further training of workers. The resulting priority of one of the most expensive alternatives—additive technologies that require processing of technological routes and replacement of machinery equipment is interest. The AHP is a useful way to deal with complex decisions. It is relatively simple, having visibility and invariance with respect to the subject area.

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