SOLVING A COMPLEX DECISION PROBLEM USING THE EXAMPLE OF DISPOSAL AND UTILIZATION OF FINE-GRAIN METAL-BEARING WASTE IN A METALLURGICAL COMPANY

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Abstract

The need for decision-making is related to management, constituting the substance thereof. Management means the wilful, purposeful influencing of a certain process, phenomenon or situation in order to achieve the required outcome or objective.

Therefore, we make decisions in the case of a deviation from the required status and if the achievement of the objective is at risk, or when we get into a situation when the objective can be achieved in several different ways. The decision-maker has a problem when he/she needs to choose the best of several alternatives to further proceed along a course.

The paper deals with the issue of disposal and utilization of fine-grain metal-bearing waste in a metallurgical company using the utility's functions.

Keywords: Decision-making; optimisation; utilization; fine-grain metal-bearing waste

1. INTRODUCTION

A problematic (decision-making) situation needs to be identified in a timely manner and the problem formulated correctly and as precisely as possible [1].

Decision-making to solve a situation assumes knowledge of the target status and current status, as well as ways and methods of changing them. Achievement of the target status is expressed by performance of one or several indicators (criteria) [2].

Various methods (alternatives) of how to achieve the object do not usually have identical consequences. We assess such consequences with respect to the chosen criteria. We require the criterion (criteria) to be able to express the degree of the (partial) objective's performance [3]. We evaluate all alternatives based on a criterion (a set of criteria) and choose the one that meets the evaluation criteria the best.

The above-mentioned characteristics result in the following basic decision-making process phases:

1) Decision problem identification and formulation,
2) Selection of decision-making criteria,
3) Creation of a set of problem solution alternatives,
4) Evaluation of the consequences of alternatives based on a set of criteria and selection of the best alternative.

To make a decision, several strategies are sometimes generated for various possible developments of the critical factors in the future [4].

Future considerations model several different developmental situations - scenarios of future development. This is why this procedure is called the scenario method. It is certainly useful to properly analyse possible future development and to get ready for it through correct decisions [5]. The number of considered development scenarios should not be so high as to impair their resolving power.

Strategic decision-making becomes an efficient tool for managers only if it is formalized to the maximum extent, leaning against high-quality information. Otherwise, it does not differ from considerations based on experience, from decision-making that is based mainly on intuition and seldom uses complex information. Such decision-making is fast and a little expensive, however, it is associated with the major risk of incorrect decisions [6].

Formalized decision-making concerning strategic problems is work-intensive; however, the costs of such decisions often represent just a minor fragment of the amounts which are being decided on, i.e. also of the losses resulting from an incorrect decision [7]. Excessive economizing would not be the right thing to do.

We will use the following example to show the strategic decision-making procedure and methods.

2. THE ISSUE OF DISPOSAL AND UTILIZATION OF FINE-GRAIN METAL-BEARING WASTE IN A METALLURGICAL COMPANY

This problem has several aspects:

- Economic - costs associated with waste disposal and utilization of metal from the waste.
- Ecological - environmental damage.
- Social - attitude of the public to solving the problem of waste, the aesthetic aspect of yards, dumping grounds, etc.

They can be used to formulate the objectives to be achieved:

1) Minimize capital expenditures for waste disposal.
2) Minimize operating costs of waste disposal.
3) Maximize utilization of metal from waste.
4) Minimize environmental damage (air, water, soil, citizens' health)
5) Minimize public discontent about the waste disposal method.

The first three objectives reflect the producers' interests, the fourth and fifth the interests of citizens and regional governments.

The following efficiency indicators (criteria) were selected for the individual objectives:
X_1 - total one-time costs (converted using the appropriate discount rate),
X_2 - waste processing costs (including eventual costs of collection),
X_3 - benefit (saving) from secondary utilization of waste as raw materials - use of Fe, Zn, Cr, etc.,
X_4 - total amount of damages,
X_5 - citizens' discontent expressed on a ten-level scale.

The above-mentioned objectives oppose one another, and, therefore, it is necessary to find the most advantageous compromise.

There are certainly several methods for utilizing the metal-bearing waste. These create alternatives to the waste problem's solutions. Preparation of such alternatives requires proper attention. It is very difficult and creative work that requires the involvement of the respective experts and the gathering of the respective information. We cannot put up with a small number of alternatives. The risk of omitting some advantageous problem-solving alternative would be too high in this case. On the other hand, time-related, financial and other reasons make us limit the decision problem by reasonable boundaries and choose such a number of investigated alternatives that enables the problem to be solved.

Using information technology, the limiting factor is not the number of alternatives, but the need to obtain all input data for such alternatives. Information technology is not able to collect such data, of course.

We consider the following methods of solving the metal-bearing waste disposal issue:

1) Isolated utilization, or waste disposal in every metallurgical company.

2) Processing of all wastes from metallurgical companies in an integrated processing company established in the region.
3) Combination of the two methods above, i.e. partial utilization of waste directly in the companies and partial processing in an integrated company.

The actual number of alternatives will be higher, because we need to consider several waste processing technology alternatives in case No. 2, and different quantities of processed waste in metallurgical companies and in the integrated company in case No. 3.

We will consider the following alternatives:

ALTERNATIVE 1

Current status of waste disposal in metallurgical companies (no investment).

ALTERNATIVE 2

Waste disposal in metallurgical companies with minimum investment.

ALTERNATIVE 3

Waste disposal in metallurgical companies with huge investment.

ALTERNATIVE 4

Processing of all wastes in an integrated company using technology A.

ALTERNATIVE 5

Processing of all wastes in an integrated company using technology B.

ALTERNATIVE 6

Processing of all wastes in an integrated company using technology C.

ALTERNATIVE 7

Waste utilization in companies corresponding to the current status and processing of the balance (not deposited yet) in an integrated company using technology A.

ALTERNATIVE 8

Waste utilization in companies corresponding to the current status and processing of the balance (not deposited yet) in an integrated company using technology B.

ALTERNATIVE 9

Waste utilization in companies corresponding to the current status and processing of the balance (not deposited yet) in an integrated company using technology C.

ALTERNATIVE 10

Minimum investment in companies and processing of a portion of the waste in an integrated company using technology A.

ALTERNATIVE 11

Minimum investment in companies and processing of a portion of the waste in an integrated company using technology B.

ALTERNATIVE 12

Minimum investment in companies and processing of a portion of the waste in an integrated company using technology C.

ALTERNATIVE 13

Higher investment in companies and processing of the waste balance in an integrated company using technology A.

ALTERNATIVE 14

Higher investment in companies and processing of the waste balance in an integrated company using technology B.

ALTERNATIVE 15

Higher investment in companies and processing of the waste balance in an integrated company using technology C.

These alternatives meet the five partial objectives to a different extent. Their advisability or inadvisability can be assessed using the “utility functions”. Each individual criterion expresses a certain aspect of the total utility. It corresponds to the respective partial utility function. It is sometimes identified as a one-dimensional utility function. The final utility is expressed by a “multi-dimensional” (total, final, aggregate) utility function. The utility functions enable quantification of the structure of values with multiple objectives.

The utility function's determination requires a creative approach. It includes the following tasks:

- verify the required conditions of independence of criteria,
- assemble one-dimensional utility functions $u_i\ (x_i)$,
- find constant values (weighing coefficients),
- determine the aggregate utility function $u = f(u_i)$.

Independence of criteria means that valuation of an alternative based on one criterion is not connected with valuation based on other criteria. The multi-dimensional utility function is rather simple with independence of the criteria, and, therefore, it is advisable to have mutually independent criteria because independence of criteria is not always obvious.

3. UTILITY FUNCTIONS

The values of the criteria for all alternatives are stated in **Table 1**. Non-recurring costs are converted by discounting to one year common for all alternatives. In case of alternatives 7 to 15, it is the sum of such costs in companies and in the integrated company.

Besides processing, the operating costs in alternatives 4 to 15 also include the costs of waste collection from the metallurgical company to the processing location in the integrated company and delivery of the usable raw materials back to the metallurgical company.

The operating costs when utilizing the waste directly in the metallurgical company are advantageously reduced by utilizing the waste heat or the heat of the waste, as such.

As far as the benefit from utilization of secondary raw materials is concerned, we can assume the biggest utilization of metal in the case of processing all wastes in a special company. The benefit mainly depends on the quantity of the waste utilized, and the amount of damage by contamination of air, water, soil and damage to citizens’ health.

The integrated company where complex waste processing is assumed using state-of-the-art technology reduces the damages to a minimum. Additional transport and handling related to collection is, however, a source of additional dust pollution.

Citizens’ discontent about the waste disposal method is expressed by a ten-level scale where the individual levels are defined in detail. An ideal solution corresponds to level 1, the worst to level 10.

Table 1 Numerical values of criteria

Criterion / Alternative	X1 (million CZK)	X2 (million CZK per year)	X3 (million CZK per year)	X4 (million CZK per year)	X5 Scale
1	0	100	150	1500	9
2	80	120	190	1200	8
3	1000	200	300	450	5
4	2000	280	500	400	4
5	1200	250	400	600	6
6	1800	300	450	650	5
7	1400	260	480	750	5
8	800	270	380	900	7
9	1200	250	400	800	6
10	1300	240	300	700	7
11	1000	230	320	800	6
12	1100	220	420	680	5
13	900	210	380	750	3
14	750	240	350	800	3
15	105	200	320	600	4
x0	0	100	500	400	3
x1	2000	300	150	1500	9

It may appear at first glance that criteria X_4 and X_5 overlap. There is no doubt that there is a certain relation; however, the citizens' attitude does not result only from the amount of damages, but from permanent and apparent effects which make life uncomfortable, have an non-estetic influence, and which annoy people.

To determine an aggregate utility, it is required to standardize the one-dimensional functions within the range from 0 to 1. The best performance of the criterion corresponds to the utility value of 1, the worst value to zero utility.

Putting the values of all criteria in properly selected scales, we can graphically illustrate the "alternative efficiency profiles". They clearly indicate how the alternatives meet the individual criteria; however, not enabling the sequence of suitability of the individual alternatives to be determined.

Looking at **Table 1**, it is obvious that no alternative is the best or the worst in all criteria. Therefore, it is not possible to directly determine the best or the worst alternative. A human is not capable of directly evaluating more alternatives concurrently from several different aspects. The graphical illustration of efficiency profiles does not help either. It is more illustrative than a table, but such illustration is disputable in the case of a higher number of alternatives. Sequences of the alternatives from the best to the worst based on the individual criteria are absolutely different.

To create multi-dimensional utility functions connecting the partial evaluations based on individual criteria into a final evaluation, it is required to further investigate the hierarchy and structure of the decision-maker's values. Such investigation will enable mutual compensation of partial evaluations and their connection to the final utility function. In order to ensure that the compensation for partial evaluations is correct, we need to know the importance which the decision-maker attaches to the individual criteria. There is a huge number of methods for determining a criterion's significance.

The point is not to determine the “objective” significance of criteria (questioning more experts), but to determine the decision-maker’s preferences for a specific case and specific values which the criteria in the individual solution's alternatives achieve.

4. DETERMINING THE SIGNIFICANCE OF CRITERIA

The purpose is to quantify the decision-making system of values in the given decision's problem. This is done by determining the values of coefficients, expressing the significance of criteria. Such coefficients are first ranked by significance and then their values are quantified.

4.1 Creating a sequence of coefficients

Comparison should not be desultory. It needs to consider the range between the best and the worst value of the criteria being compared. With a higher number of criteria and a comparison of all pairs, we may find an inconsistency between the partial results. And this also happened in our case.

Table 2 Arrangement of individual criteria

Conflicting arrangement	Corrected arrangement
$k_2 > k_1$	$k_2 > k_1$
$k_3 > k_1$	$k_3 > k_1$
$k_4 > k_1$	$k_4 > k_1$
$k_1 > k_5$	$k_5 > k_1$
$k_3 > k_2$	$k_3 > k_2$
$k_4 > k_2$	$k_4 > k_2$
$k_5 > k_2$	$k_5 > k_2$
$k_4 > k_3$	$k_4 > k_3$
$k_3 > k_5$	$k_3 > k_5$
$k_4 > k_5$	$k_4 > k_5$

The corrected non-conflicting arrangement gives us the following sequence of criteria significance:

$X_4\ X_3\ X_5\ X_2\ X_1$

The following relations will be set between the coefficient values:

$k_4 > k_3 > k_5 > k_2 > k_1$

Weighing coefficients are quantified by a dialogue between the analyst and decision-maker with the following results:

The following sets of equations are available for coefficients ki:

$k_1 = 0.5*k_4$ $k_2 = 0.75*k_4$ $k_3 = 0.945*k_4$ $k_5 = 0.825*k_4$

We determine value k4 as follows:

We ask the decision-maker a question: at what value of probability p is the determined consequence with the best value of $x_4 = 400$ equal for you? The decision-maker sets $p = 0.25$.

$k_4 = p = 0.25$

We can use the equations for the other ki to easily calculate:

$k_5 = 0.825*0.25 = 0.206$ $k_3 = 0.945*0.25 = 0.236$

k_2 = 0.75*0.25 = 0.188 k_1 = 0.5*0.25 = 0.125

Now we add up all coefficients ∑ k_i = 1.005. The resulting utility function will have the following form given by the following relation:

$$u(X_1,X_2,X_3,X_4,X_5) = \sum_{i=1}^{5} k_i u_i(x_i) \quad (1)$$

Round coefficients k_i so that their sum is exactly 1.

k_1 = 0.125 k_2 = 0.187 k_3 = 0.234 k_4 = 0.25 k_5 = 0.204

5. CALCULATION OF UTILITY FUNCTIONS

Introducing into formula (1), we will specify the summary utility function for all 15 alternatives and will find the optimal alternative among them.

$u_1(x_i)$ = 0.125*1 + 0.187*1 + 0.234*0 + 0.25*0 + 0.204*0 = 0.312

$u_2(x_i)$ = 0.125*0.96 + 0.187*0.9 + 0.234*0.205 + 0.25*0.408 + 0.204*0.167 = 0.472

$u_3(x_i)$ = 0.125*0.5 + 0.187*0.5 + 0.234*0.58 + 0.25*0.973 + 0.204*0.667 = 0.671

$u_4(x_i)$ = 0.125*0 + 0.187*0.1 + 0.234*1 + 0.25*1 + 0.204*0.833 = 0.673

$u_5(x_i)$ = 0.125*0.4 + 0.187*0.25 + 0.234*0.81 + 0.25*0.885 + 0.204*0.5 = 0.610

$u_6(x_i)$ = 0.125*0.1 + 0.187*0 + 0.234*0.91 + 0.25*0.855 + 0.204*0.667 = 0.575

$u_7(x_i)$ = 0.125*0.3 + 0.187*0.2 + 0.234*0.964 + 0.25*0.79 + 0.204*0.667 = 0.634

$u_8(x_i)$ = 0.125*0.6 + 0.187*0.15 + 0.234*0.77 + 0.25*0.67 + 0.204*0.333 = 0.519

$u_9(x_i)$ = 0.125*0.4 + 0.187*0.25 + 0.234*0.81 + 0.25*0.75 + 0.204*0.5 = 0.576

$u_{10}(x_i)$ = 0.125*0.35 + 0.187*0.3 + 0.234*0.58 + 0.25*0.825 + 0.204*0.333 = 0.510

$u_{11}(x_i)$ = 0.125*0.5 + 0.187*0.35 + 0.234*0.63 + 0.25*0.75 + 0.204*0.5 = 0.565

$u_{12}(x_i)$ = 0.125*0.45 + 0.187*0.4 + 0.234*0.85 + 0.25*0.837 + 0.204*0.667 = 0.675

$u_{13}(x_i)$ = 0.125*0.55 + 0.187*0.45 + 0.234*0.77 + 0.25*0.79 + 0.204*1 = 0.735

$u_{14}(x_i)$ = 0.125*0.625 + 0.187*0.3 + 0.234*0.7 + 0.25*0.75 + 0.204*1 = 0.690

$u_{15}(x_i)$ = 0.125*0.475 + 0.187*0.5 + 0.234*0.63 + 0.25*0.885 + 0.204*0.883 = 0.691

Alternative 13 appears to be the optimal one, as its aggregate utility achieved the maximum value of 0.735. This is followed by alternatives 15 and 14 with utilities 0.691 and 0.690.

Building only an integrated plant is ranked in the 5th, 8th and 10th positions based on the technology chosen (utility of 0.673, 0.610 and 0.575).

It appears that it is the most advantageous to process a portion of the waste in the integrated plant and a portion directly in the metallurgical company.

The above-mentioned solution is based on a statistical view of the problem. The time factor is respected only for conversion of the non-recurring costs to a comparable base.

When making a decision on matters with consequences which become evident over a longer period of time (10 years and more), a short-term view of the problem (static model) is not sufficient and it is required to conduct a dynamic analysis and assess the solution's alternatives in the long term.

6. CONCLUSION

Building a metallurgical waste processing plant is a problem that requires such an approach. This is given by the fact that the plant to be built will not operate for a short period of time. It needs to be considered to remain operating for more than 10 years.

The metallurgical production conditions, and thus the production of waste, may change over a longer period of time. Such future does not currently appear as uniquely determined, but it may significantly change owing to circumstances. In this respect, the metallurgical production may increase, remain unchanged or decrease. Another unknown comprises changes in the production technologies applied which may significantly change the production and form of waste. Changes may also occur in the composition of the charged material for metallurgical production. All of these are the most critical changes on the part of metallurgy.

ACKNOWLEDGEMENTS

The work was supported by the specific university research of Ministry of Education, Youth and Sports of the Czech Republic No. SP2017/67.

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