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Selection of Technological Processes from the Standpoint of LOW-AND NON-WASTE TECHNOLOGY for Industrialization Projects

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In connection with industrialization projects the correct selection of a technological process among several possible variants for meeting an existing demand of national economy from the standpoint of LNWT is of outstanding importance.

A precise way of evaluating technological processes in order to develop and to introduce LNWT, theoretically would be by cost-benefit-analysis. In this connection not only technological and economic influences should be taken into consideration but also ecological and social aspects. The question of monetary evaluation of environmental impacts and similar effects, however, has not yet been solved at the international level. Therefore other ways must be sought for evaluating technological processes.

For that reason by the European Economic Commission already in December 1984 a manual was published, which was elaborated by a special task force of the EEC under the leadership of the TU Dresden. In the years since 1984 the method offered in the manual was tested and completed especially for industrialization purposes in developing countries.

The method developed may be used

- to compare several technological processes (at least two) for the production of a defined product,
- to evaluate the processes from the standpoint of LNWT and
- to make a clear choice-which process variant should be prefered because of its technological, economic, ecological and social characteristics

depending on national economic conditions as well as regional or local prerequisites, respectively.

The developed method bases on selected characteristics, which are grouped to a minimum programme, characterizing the technological process and-if necessary-the aimed main product from the standpoint of LNWT (see Fig.1).

In connection with the preparation of an investment decision only such characteristics of the minimum programme are allowed to be neglected which are not suitable (e.g. if there is no air pollution or water pollution etc.).

The estimation of the characteristics is carried out on the basis of a foregoing Auditing of the technological variants for the special process.

Figure 1. Characteristics for Evaluation of Technology

Fig. 2 shows the sequence of the working steps of the selection method, which represents a combination of evaluating as well as weighting the given characteristics.

For evaluating the characteristics against the background of a world level analysis there are estimated for each characteristic

- the Zero-Value, K_0 (accepted worst value) and
- the Best-Value, K_B (best possible value).

The ealuation is calculated by the equation

$$PW=\frac{Ko-K}{Ko-K_B}$$

Where K-Real-Value of the given characteristic.

This delivers values for all characteristics for all technological variants under discussion within a given industrialization project.

For weighting the characteristics according to Fig.2 a group of experts is formed consisting of

4(2) technologists,

4(2) economists,

4(2) ecologists and specialists of territorial planning.

All the 12(6) experts should be skilled specialists in their profession or their fields of activity, respectively, with long-time experiences, the private intersts of which are not connected in any way with the intersts of the enterprise ordering the selection procedure.

After a total information of the experts' group about advantages and disadvantages of the technological variants under discussion as well as the conditions within the region and the whole national economy each expert gets a questionary, which contains the characteristics grouped for a paired comparison according to Fig. 3.

Each expert separtely marks in each pair of characteristics, which of them from his point of view in the given case should get a higher importance. On the basis of the experts' decisions made by this paired comparison a personal preference table is compiled for each expert.

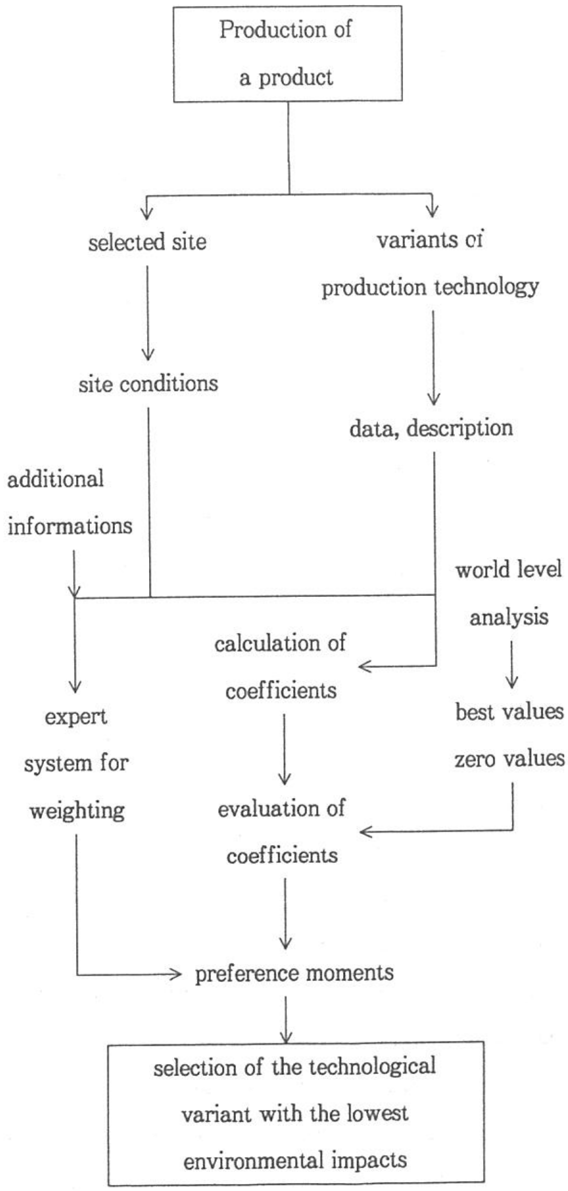

Figure 2. Working Steps for Evaluation of Technology

K 1 K 2	K15 K11	K15 K 1	K10 K 7
K16 K 6	K14 K12	K 7 K 6	K11 K 6
K15 K 7	K13 K 1	K 8 K 5	K12 K 5
K14 K 8	K 5 K 4	K 9 K 4	K13 K 4
K13 K 9	K 6 K 3	K10 K 3	K14 K 3
K12 K10	K 7 K 2	K11 K 2	K15 K 2
K11 K 1	K11 K16	K15 K16	K 1 K 9
K 3 K 2	K12 K 9	K 1 K 7	K 8 K10
K 7 K16	K13 K 8	K 6 K 8	K 7 K11
K 8 K16	K12 K15	K 5 K 9	K 6 K12
K 9 K14	K13 K14	K 4 K10	K 5 K13
K10 K13	K 1 K 5	K 3 K11	K 4 K14
K11 K12	K 4 K 6	K 2 K12	K 3 K15
K 1 K 3	K 3 K 7	K16 K 1	K 2 K16
K 2 K 4	K 2 K 8	K 8 K 7	K10 K 9
K16 K 8	K16 K12	K 9 K 6	K11 K 8
K15 K 9	K15 K13	K10 K 5	K12 K 7
K14 K10	K14 K 1	K11 K10	K13 K 6
K13 K11	K 6 K 5	K14 K 7	K14 K 5
K12 K 1	K 7 K 4	K11 K 4	K15 K 4
K 3 K 4	K 8 K 3	K12 K 3	K16 K 3
K 2 K 5	K 9 K 2	K13 K 2	K 1 K10
K16 K 9	K13 K16	K 1 K 8	K 9 K11
K15 K10	K14 K15	K 7 K 9	K 8 K12
K14 K11	K 1 K 6	K 6 K10	K 7 K13
K13 K12	K 5 K 7	K 5 K11	K 6 K14
K 1 K 4	K 4 K 8	K 4 K12	K 5 K15
K 3 K 5	K 3 K 9	K 3 K13	K 4 K16
K 2 K 6	K 2 K10	K 2 K14	K15 K 6
K16 K10	K16 K14	K 9 K 8	K16 K 5

Fig. 3. Questionary for weighting the characteristics by paired comparison (ROSS-method)
(pairs of characteristics containing characteristics not relevant in the given case may be neglected)

The judgements shown in all the experts' decisions are tested by the consistency coefficient:

$$K=1-\frac{24d}{n^3-4n}\ (if\ n\ is\ an\ even\ number)$$

$$K=1-\frac{24d}{n^3-4n}\ (if\ n\ is\ an\ uneven\ number)$$

$$d=\frac{n(n-1)\ (2n-1)}{12}-\frac{\sum a^2}{2}$$

a—weight of the characteristics given by an expert

n—number of characteristics

K—consistency coefficient

Generally a threshold of

K=0.8

is assumed as sufficient.

Therefore the requested minimum value of $\sum a^2$ may be estimated as follows:

n	$\sum a^2$
10	269
11	363
12	478
13	614
14	774
15	959
16	1173

where n-number of relevant characteristics.

This test is carried out for the personal preference table of each expert. In the case of insufficient competency or bad information, if a clear decision is not guaranteed, the threshold of $\sum a^2$ will not be reached.

After checking the consistency of the experts' decisions, a combined preference table is arranged. For this purpose the values for all characteristics are summarized.

Table 1.

χ^2 — Distribution function

$\chi^2=\chi^2(\alpha,f)$

α = error probability

f = degrees of freedom

f	α error probability 0.30	0.10	0.05	0.025	0.01	0.001
1	1.07	2.71	3.84	5.02	6.4	10.8
2	2.41	4.61	5.99	7.38	9.21	13.8
3	3.67	6.25	7.81	9.35	11.3	16.3
4	4.88	7.78	9.49	11.1	13.3	18.5
5	6.06	9.24	11.1	12.8	15.1	20.5
6	7.23	10.6	12.6	14.4	16.8	22.5
7	8.38	12.0	14.1	16.0	18.5	24.3
8	9.52	13.4	15.5	17.5	20.1	26.1
9	10.7	14.7	16.9	19.0	21.7	27.9
10	11.8	16.0	18.3	20.5	23.2	29.6
11	12.9	17.3	19.7	21.9	24.7	31.3
12	14.0	18.5	21.0	23.3	26.2	32.9
13	15.1	19.8	22.4	24.7	27.7	34.5
14	16.2	21.1	23.7	26.1	29.1	36.1
15	17.3	22.3	25.0	27.5	30.6	37.7
16	18.4	23.5	26.3	28.8	32.0	39.3
17	19.5	24.8	27.6	30.2	33.4	40.8
18	20.6	26.0	28.9	31.5	34.8	42.3
19	21.7	27.2	30.1	32.9	36.2	43.8
20	22.8	28.4	31.4	34.2	37.6	45.3

$$\sum_{i=1}^{12} a_{ij}=R_j$$

where i — number of experts (1…12) or (1…6),

j — number of characteristics (1…16),

a — weight of characteristic given by one expert,

R — weight of a characteristic summarized from the weights given by the single experts, combined preference of a characteristic.

On the basis of these combined preferences, initially the significance level of the estimated preferences has to be checked. The KENDAL-agreement coefficient is estimated as:

W>0: Agreement on the experts' weighting results is not based on random effects.

W=0: No connection between preferences from the experts' weighting.

The significance level is checked by means of a χ^2-test:

$$\chi^2>\chi^2 \text{ critical}$$

$$\chi^2=K(n-1)W$$

$$W=\frac{\sum_{j=1}^{n}(R_j-R)^2}{\frac{K^2(n^3-n)}{12}}$$

$$R=\frac{K(n+1)}{2}-K$$

where K — number of experts,

n — number of characteristics,

W — KENDAL's agreement coefficient.

The significance test is based on the assumption that the quality of the preference calculation follows a certain distribution pattern. For n=7…30 this distribution may be approximated by the χ^2−distribution with (n-1) degrees of freedom (see Tab.1). Because of the statistical character of the test, a defined risk-expressed by the probability level or the error probability, respectively-must be accepted. The threshold value is stated before the test.

The χ^2−test demonstrates that the finding

W>O: Agreement of the experts' weighting results is not based on random effects.

Generally an error probability of α=5%(95% significancy) is accepted. The result

W=O: No connection between the preference from the experts' weighting

normally cannot be expected.

The next step consists of relating the values of the characteristics and their combined weights (or preferences) to so-called preference moments. These preference moments are summarized within each variant of the technological process for all characteristics. This delivers a total preference moment for each technological variant. The variant with the highest preference moment represents the best one from the standpoint of LNWT.

In former years, by the fact that the weighting was carried out by a team of qualified experts, there was a lot of critic because there seemed to be a possibility of subjectivity. By introducing an expert system this problem could be eliminated.

An expert system was developed, which consists of an especially elaborated knowledge base. This knowledge in narrow cooperation with the psychologists of the TU Dresden was collected by means of special interviews and tests from a large group of well known experts in the field of environmental engineering and environmental protection. The expert system at present contains several hundred questions, which are structured into several thousand decision paths. By means of this expert system the above mentioned parameters are weighted according to their specific importance. The decision maker in a dialogue with the computer, which gives him all necessary questions to be answered clearly, is lead to the conclusion : Which technological variant among the possible technologies should be selected under the applying conditions for the given site?

The main field of application of the developed method for EIA within investment decisions for industrialization is the wide range of engineering consulting and environmental consulting in all branches of industry. The method represents a help for the engineer, which has to realize a technological plant to produce a product for the market with ecological consequences and disadvantages as low as possible but also at investment and operational costs as low as possible. Mostly this delivers an economic-ecological conflict situation. By the given evaluation method it is possible to eliminate this conflict.

The present selection method from the standpoint of LNWT shows a high applicability in a series of tests. The main work represents the collection of necessary information by system analysis and eco-auditing. If all these data are given, the whole evaluation process, including weighting by a group of experts or a computer based procedure takes only a few hours.

The statement of the preference moments is unique. From the results of the evaluation method it may be concluded that because of its characteristics a given technological variant cannot be selected.

If single preference moments of special characteristics are awarded zero, this infers that they do not contribute to the total preference moment of a technological variant from the standpoint of LNWT. Characteristics with zero preference moments must be improved to make this technological variant competitive with other variants. The evaluation method can also be used in preparing decisions on planning further works for investigation and development of technological processes.

If the decision is made by use of an experts' group, the statistical tests included in the evaluation procedure, tests of consistency and estimation of probability level of the agreement coefficient, provide a high degree of security within the evaluation method. Information deficiency, subjectivity and bias are eliminated. If these effects appear because of negative results from the tests mentioned above, the evaluation is to be stopped and repeated on the basis of better conditions of the experts' competency these problems do not exist, because a computer does not have a personal opinion.

The present method may be applied also to problems of site selection. For this purpose, however, specific characteristics must be developed. The application of the method to problems of site selection has been tested in connection with the erection of an industrial complex in a developing country.