# APPLICATION OF THE ANALYTIC HIERARCHY PROCESS IN THE PROCESS OF DECISION-MAKING WITHIN THE SCOPE OF ECO-LOGISTICS

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**Abstract**: In this paper we give a short overview about the problems of the choice of eco-logistic solution in company. The definition of eco-logistics tells us that what it deals with is the flows of pollution and waste materials. Eco-logistics realizes both economic and ecological goals which in a long run may become convergent. In order to find the best option for solving the problem of functioning of eco-logistics in a company, the decision-maker should take into consideration many criteria – economic as well as ecological. The intricacy of the problem consisting in the multiplicity of its criteria imposes the choice of the method applied to tackling it. The analytic hierarchy process is one of the procedures which can be use in problems solution.

**Keywords**: Logistics, eco-logistics, analytic hierarchy process, decision optimisation

The processes of environmental protection conducted by companies should be integrated with the general management system. It is rendered possible through the introduction of the concept of sustainable development to companies' activities. Concentrating on the questions concerning ecological development incorporates choosing particular strategies and structures, as well as a certain kind of culture. Thereby a new branch of logistics arises – eco-logistics. It is an integrated system of the flow of waste and interrelated information, which reassures optimal ways of production and transformation of commodities. The chief aim of eco-logistics is to recognize and abide by the standards required of environmental protection with simultaneous preservation of the standards of economy and commodities' quality.

Eco-logistics is usually presented at the end of logistics system. It stems out from the fact that eco-logistics has to do with by-products which also appear at the end of the production process. The task of eco-logistics is to scale down the amount of produced waste. It is only possible over its coordination with other logistics subsystems. It is directly connected with the principle of waste neutralization at its source which determines following hierarchy of methods applicable to this task:

- to avoid emission of pollution through restructuring production and consumption systems in the view of providing lesser pressure on the environment.
- to take advantage of recycling which consists in the creation of closed circulation systems for materials and raw materials, recovery of energy, water and raw materials from sewage and waste, economic use of waste instead of its disposal into the environment

- to neutralize pollution, conduct sewage treatment and emitted gases, neutralize and warehouse solid waste

Thus optimal management of waste concerns:

- avoiding production of waste (especially dangerous waste) in the activities of companies
- decreasing the amount of waste
- repeated use of waste

The definition of eco-logistics tells us that what it deals with is the flows of pollution and waste materials. This makes primary difference between eco-logistics and other logistics subsystems (conf. figure 1). Moreover, the directions of the flows are different as well. Products, as the objects of other subsystems, move from suppliers to recipients, while waste passes from where it is produced to the units where it is utilized or liquidated.

| Subsystems of logistics according to the phases of objects' flows | Objects | Directions of flows | Types of the goals of a subsystem | Chosen ecological goals |
|---|---|---|---|---|
| Logistics of supply | Materials, commodities, semi-products, final products | From supplier to purchaser | Economic and ecological goals | Selection of an ecological supplier |
| | | | | Use of ecological means of transport |
| Logistics of production | Materials, commodities, semi-products, final products | | | Use of environment-frindly packagings |
| | | | | Planning of ecological transport |
| Logistics of distribution | Products | | | |
| Logistics of spare parts | Spare parts | | | Increase of the efficiency of repeated use through e.g. waste sorting |
| Waste management logistics (eco-logistics) | Waste and pollution | From the place of creation to the units of utilization or liquidation | | |

Fig. 1 Eco-logistics vs. their logistics subsystems
(Source: own elaboration on the basis of [2.])

Eco-logistics realizes both economic and ecological goals which in a long run may become convergent. Literature of the subject abounds in a profusion of views which to a lesser or greater extent put emphasis on the categories mentioned above. Accordingly, the goals of eco-logistics may be perceived in a variety of ways [2.]:

- avoidance of waste (especially dangerous waste), decrease of the amount of waste and its second introduction to the economic circulation.
- Controlling the flow of materials in the production phase and the decrease of the amount of waste
- making the processes economical and reduce the level of risk as an economic goal and the preservation of resources and reducing the pressure on the environment

None of these views precisely determines the structure or links between ecological and economic goals. Pfohl and Stölzle differentiate economic and ecological goals of eco-logistics on material and formal tiers and show relations between them. Main economic goals of eco-logistics are connected with decreasing the costs of logistics and enhancing customer service. Thus these goals can refer to the goals of logistics, taking into account, however, their importance for ecologically oriented concept of logistics. Ecological goals are connected with the aims of environmental protection and are understood as the whole of logistics processes in environmental protection which are preservation of resources and reduction of pollution [2.]. The goals of eco-logistics should complement the objectives of waste management. Therefore, a matter of great importance is the avoidance and reduction of waste. Attainment of this goal is only possible through the interaction of eco-logistics with other functional fields of logistics. The most important strategic objective of economy is repeated use of waste. In this respect, the goal of eco-logistics is to overcome the differences between the amounts of waste which is produced and repeatedly used. Eco-logistics will be directly connected with the realization of this aim. Another strategic goal of eco-logistics is proper disposal of waste which is understood as both its proper storage and liquidation.

The integration of economic and ecological goals can be done in three ways [2.]:
1. environmental goals will be deemed as a restriction issued by superior authority
2. ecological goals will at the same time be economic goals
3. environmental protection will be introduced as a separate, autonomic part of companies' management and will be equally important to economic goals

Accordingly, we distinguish three levels of the introduction of ecological processes to the system of companies' objectives [1.]:
1. eco-standard – companies adjust their management so that it corresponds to minimal legal requirements connected with environmental standards
2. eco-actions – companies carry out some actions beneficial for the environment on their own
3. eco-specialization – companies thanks to their ecological awareness and knowledge about market laws treat the ecological criterion as the basis of their existence

In order to find the best option for solving the problem of functioning of eco-logistics in a company, the decision-maker should take into consideration many criteria – economic as well as ecological. The intricacy of the problem consisting in the multiplicity of its criteria imposes the choice of the method applied to tackling it. The analytic hierarchy process[1] (AHP) is based on the theory of usefulness which consists in relating a normalized evaluation to every variant. The evaluation is interpreted as the level of usefulness of variants. Normalized final evaluations of every option give us the vector of the scale of decision to be made. Obtaining the final value allows us to rank the variants and to choose the best one.

Let us assume that a company wants to adjust its product (within the scope of recycling) to the environmental protection standards. There are three possible ways of realizing this goal:
1. introduction of clean production technology and recycling of materials as part of the production process
2. scale-down the amount of generated waste through:
   - decrease of the amount of raw materials used
   - use ecological raw materials in production process
   - change of the physical properties of products in order to adjust them to recycling

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[1]          The Analytic Hierarchy Process was presented on the basis of [3.]

3. introduction of the system of selective collection of waste in every stage of activity to prepare the waste for recycling understood as a service provided by an exterior unit.

The decision-maker has to consider five criteria concerning economic and ecological goals:
1. costs of the realization of the undertaking
2. the amount of waste which will not be appropriate for repeated use
3. realizing customers' expectations connected with the environment-friendly product
4. enhancing cooperation between employees from different departments with respect to environmental protection
5. enhancing the relationships between companies and local community

The problem of the multiplicity of criteria that have to be taken into consideration brings about the need for use of analytic hierarchy process. On the basis of pair comparison of criteria a matrix of comparisons (matrix A) was built (table 1).

Table 1 Matrix of pair comparison (Source: own elaboration)

|           | $f_1$ | $f_2$ | $f_3$ | $f_4$ | $f_5$ |
|-----------|-------|-------|-------|-------|-------|
| $f_1$     | 1     | 4     | 4     | 7     | 7     |
| $f_2$     | 1/4   | 1     | 4     | 6     | 6     |
| $f_3$     | 1/4   | 1/4   | 1     | 3     | 4     |
| $f_4$     | 1/7   | 1/6   | 1/3   | 1     | 2     |
| $f_5$     | 1/7   | 1/6   | 1/4   | 1/2   | 1     |
| $\sigma_j$ | 1,786 | 5,583 | 9,583 | 17,5  | 20    |

To count the scale's vector for the criteria, Saaty's method was used which consists of following stages:
1. For every column of matrix A elements $\sigma_j$ was counted through the formula:

$$\sigma_j = \sum_{i=1}^{m} \alpha_{ij} \tag{1}$$

Where:

$\alpha_{ij}$     - element of matrix A

m     - criteria number

2. A normalized matrix $B=[\beta_{ij}]_{i,j=1,2,...,m}$ (table 2) was built whose elements in column j were counted through formula:

$$\beta_{ij} = \frac{\alpha_{ij}}{\sigma_j} \tag{2}$$

3. Approximate vector b was counted (table 2) as the average from the row of normalized matrix using formula:

$$b_i = \frac{1}{m} \left( \sum_{j=1}^{m} \beta_{ij} \right) \tag{3}$$

Table 2 Matrix B and scale vector b (Source: own elaboration)

|       | $f_1$  | $f_2$  | $f_3$  | $f_4$  | $f_5$  | b      |
|-------|--------|--------|--------|--------|--------|--------|
| $f_1$ | 0,560  | 0,716  | 0,417  | 0,400  | 0,350  | 0,489  |
| $f_2$ | 0,140  | 0,179  | 0,417  | 0,343  | 0,300  | 0,276  |
| $f_3$ | 0,140  | 0,045  | 0,104  | 0,171  | 0,200  | 0,132  |
| $f_4$ | 0,080  | 0,030  | 0,035  | 0,057  | 0,100  | 0,060  |
| $f_5$ | 0,080  | 0,030  | 0,026  | 0,029  | 0,050  | 0,043  |

4. Average value $\lambda_{max}$ was counted through formula:

$$\lambda_{max} = \frac{1}{m}\left( \sum_{i=1}^{m} \frac{(Ab)_i}{b_i} \right)$$

(4)

In order to do this matrix Ab was counted:

$$
\begin{bmatrix}
1 & 4 & 4 & 7 & 7 \\
1/4 & 1 & 4 & 6 & 6 \\
1/4 & 1/4 & 1 & 3 & 4 \\
1/7 & 1/6 & 1/3 & 1 & 2 \\
1/7 & 1/6 & 1/4 & 1/2 & 1
\end{bmatrix}
\times
\begin{bmatrix}
0,489 \\
0,276 \\
0,132 \\
0,060 \\
0,043
\end{bmatrix}
=
\begin{bmatrix}
2,843 \\
1,546 \\
0,676 \\
0,306 \\
0,222
\end{bmatrix}
$$

which resulted in:

$$\lambda_{max} = 5,356$$

5. Index of accordance was counted whose aim is to check to what an extent the evaluations of the decision-maker from matrix $A=[\alpha_{ij}]_{i,j=1,2,\ldots,m}$ are coherent using formula:

$$c = \frac{\lambda_{max} - m}{r(m-1)}$$

(5)

where r is the number from table 3 of values of accordance indices, which resulted in:
$$c = 0,080,$$
which shows that the evaluations are in accordance (if $c > 0,1$, pair comparisons have to be performed once again)

Table 3 accordance indices (Source: [3.])

| m | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
|---|------|------|------|------|------|------|------|------|
| r | 0,58 | 0,90 | 1,12 | 1,24 | 1,32 | 1,41 | 1,45 | 1,49 |

Next, for each criterion $j = 1, 2, …, n$ a matrix of comparisons of variants was built in respect of $j$ criterion. In order to find the scale vector in respect of $j$ criterion Saaty's method was used. The vector that resulted from this was given the symbol $b^j$. Variants were compared in respect of the first criterion ($j = 1$). Because of the fact that the values of the first criterion are given as real numbers, the scale vector was counted as normalized values of the first criterion and was presented in table 4.

Table 4 scale vector in respect to the first criterion
(Source: own elaboration)

|  | $f_1(a^i)$ | $b^1$ |
|---|---|---|
| $a_1$ | 54 | 0,519 |
| $a_2$ | 35 | 0,337 |
| $a_3$ | 15 | 0,144 |
| total | 104 | 1 |

6. We follow the same procedure in respect to the second criterion. The results are presented in table 5.

Table 5 scale vector in respect to the second criterion
(Source: own elaboration)

|  | $f_1(a^i)$ | $b^2$ |
|---|---|---|
| $a_1$ | 256 | 0,200 |
| $a_2$ | 369 | 0,287 |
| $a_3$ | 658 | 0,513 |
| total | 1283 | 1 |

The results of the comparisons of variants in respect to the third criterion ($j = 3$) and the scale vector were depicted in table 6.

Table 6 scale vector in respect to the third criterion
(Source: own elaboration)

|  | $a_1$ | $a_2$ | $a_3$ | $b^3$ |
|---|---|---|---|---|
| $a_1$ | 1 | 1/2 | 1/9 | 0,200 |
| $a_2$ | 2 | 1 | 1/2 | 0,288 |
| $a_3$ | 9 | 2 | 1 | 0,513 |

Characteristic value and the accordance index:

$$\lambda_{max} = 3,075$$
$$c = 0,064$$

The results of the comparisons of variants in respect to the fourth criterion ($j = 4$) and the scale vector were depicted in table 7.

Table 7 scale vector in respect to the fourth criterion
(Source: own elaboration)

|       | $a_1$ | $a_2$ | $a_3$ | $b^4$ |
|-------|-------|-------|-------|-------|
| $a_1$ | 1     | 6     | 7     | 0,739 |
| $a_2$ | 1/6   | 1     | 3     | 0,179 |
| $a_3$ | 1/7   | 1/3   | 1     | 0,082 |

Characteristic value and the accordance index:

$$\lambda_{max} = 3,102$$
$$c = 0,088$$

The results of the comparisons of variants in respect to the fifth criterion ($j = 5$) and the scale vector were depicted in table 8.

Table 8 scale vector in respect to the fifth criterion
(Source: own elaboration)

|       | $a_1$ | $a_2$ | $a_3$ | $b^5$ |
|-------|-------|-------|-------|-------|
| $a_1$ | 1     | 5     | 6     | 0,707 |
| $a_2$ | 1/5   | 1     | 3     | 0,201 |
| $a_3$ | 1/6   | 1/3   | 1     | 0,092 |

Characteristic value and the accordance index:

$$\lambda_{max} = 3,096$$
$$c = 0,083$$

Matrix C was counted whose columns comprise scale vectors for particular criteria

$$C = \begin{bmatrix} 0,519 & 0,200 & 0,098 & 0,739 & 0,707 \\ 0,337 & 0,288 & 0,254 & 0,179 & 0,201 \\ 0,144 & 0,513 & 0,647 & 0,082 & 0,092 \end{bmatrix}$$

Final vector of the allowed solutions was counted:

$$b_k = Cb$$

$$b_k = \begin{bmatrix} 0,397 \\ 0,297 \\ 0,306 \end{bmatrix}$$

What should be treated as the best decision, according to the accepted criteria, is the realization of the first concept. The second concept would result in the least desirable effects.

The application of the analytic hierarchy process to solving problems connected with decision-making will bring about following benefits:
1. taking into consideration different, very often discrepant criteria in the evaluation of proposed undertakings
2. evaluation in respect to quantitative and qualitative criteria
3. enhancement of decision-making processes

Bearing in mind the listed benefits the application of AHP is especially advisable in eco-logistics because:
1. in the decision-making processes it takes into consideration many criteria which determine economic as well as environmental goals
2. at every stage of production processes in a company, eco-logistics has links with other systems
3. there occur problems with the realization goals of particular logistic subsystems

in the evaluation of undertakings it deals with values which can be scaled as well as with those which cannot.

## References

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