A Multi-Criteria Evaluation Framework for Fish Farms

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Abstract: This paper presents a multi-criteria evaluation framework which integrates the Analytical Hierarchy Process (AHP) and the Simple Additive Weighting (SAW) methods. This approach takes into consideration subjective judgments of the decision makers. The criteria weights are calculated by using the AHP method. Subsequently, rankings of the alternatives are determined by the SAW method. Our multi-criteria evaluation framework is used for evaluating the performance of a fish farm, called Malina, located near the villages Sendreni and Smardan, Galati county, Romania. The analysis ranks the performance of the fish farm over a period of seven years, so the output is a trend over time reflecting the progress of the fish farm. The proposed framework enables the decision makers to better understand the whole evaluation process. It provides a more accurate, effective, and systematic evaluation tool.

Keywords: evaluation framework, multi-criteria model, AHP, SAW, fish farm.

1. Introduction

Legislation requires that fisheries should be managed according to the principles of ecologically sustainable development. This imposes a complex set of potentially conflicting, multiple objectives. Primary considerations in fisheries management are: (i) sustainability of the resource base, (ii) economic viability and (iii) equity in access to the resource.

One of the reasons of management failure in fisheries is the conflict between ecological constraints and social and economic priorities, the latter often having priority over resource conservation. Moreover, fisheries management issues (stock evaluation, recruitment process, catches, eco-systemic effects, etc.) are highly marked by uncertainty. An important issue is thus to determine management procedures that give acceptable results with respect to the sustainability objectives while being robust to uncertainties [11], [12].

In this paper, we present a multi-criteria evaluation framework which integrates the Analytical Hierarchy Process (AHP) and the Simple Additive Weighting (SAW) methods. This approach takes into consideration subjective judgments of the decision makers. The criteria weights are calculated by using the AHP method. Then rankings of the alternatives are determined by the SAW method. Our multi-criteria evaluation framework is used for evaluating the performance of a fish farm, called Malina, located near the villages Sendreni and Smardan, Galati county, Romania. About 127 ha out of a total fishery area of 131 ha are covered by water. The analysis ranks the performance of the fish farm over a period of seven years so the output is a trend over time reflecting the progress of the fish farm.

The proposed framework enables the decision makers to understand better the whole evaluation process. It provides a more accurate, effective, and systematic evaluation tool.

2. A Multi-criteria Evaluation Frame-Work

Multi-Criteria Decision Making (MCDM) methods consist in finding the “best” alternative from all of the feasible alternatives in the presence of multiple, usually conflicting, decision criteria. The MCDM methods are classified into multi-attribute decision methods – MADM and multi-objective decision methods – MODM.

Many objectives for fisheries management have been suggested [3]. Among the most frequently mentioned objectives are: (i) maximum employment, (ii) maintaining regional habitation, (iii) maximum sustainable yield, (iv) conservation of fish stocks and the environment, (v) economic efficiency, and (vii) social equity. Clearly, not all of these objectives are independent. The observation that several different objectives have been proposed for fisheries suggests that fisheries management may be seen as a problem in multi-objective maximization. To solve problems of this kind, techniques have been developed [1], [2], [4], [6], [17]. A multi-objective portfolio selection model for fisheries management is presented in [10].

A typical application of multi-attribute decision methods involves a fixed number of alternatives and a set of criteria that are to be satisfied. Instead of using multi-criteria analysis to choose between several alternative courses of action, the framework is used here to compare performance at different points in time for a fish farm. The analysis ranks the performance of a fish farm over the years (or other convenient units of time). Multi-criteria analysis involves the explicit inclusion of subjective weights.

One of the most outstanding MCDM approaches is the Analytic Hierarchy Process (AHP) [13], [14], which has its roots in obtaining the relative weights among the factors and the total values of each alternative based on these weights. In comparison with other MCDM methods, the AHP method has widely been used in multi-criteria decision-making and has been applied successfully in many practical decision-making problems [14].

AHP has been widely used in fisheries where studies have largely determined the relative importance of different management objectives [8], [9] or preferences for different management options [7], [16]. It has also been used to compare the sustainability of alternative fishing fleets [18].

Within the AHP framework, a problem is represented in a hierarchical form, a multi-level structure with the goal at the top followed successively by levels of factors, criteria, sub-criteria, and alternatives. This AHP framework can be integrated with some programming tools as a complementary form, for instance, mathematical programming techniques (linear programming, integer linear programming, mixed interlinear programming, and goal programming); QFD (quality function deployment); meta-heuristics (including artificial neural networks and genetic algorithms); SWOT (strengths, weaknesses, opportunities and threats); DEA (data envelopment analysis); and fuzzy theory.

The proposed evaluation framework contains the following steps:

- Identification of the evaluation criteria
- Make pair-wise comparison and check consistency
- Calculate criteria weights
- Decision matrix construction
- Alternatives ranking

Each step of the evaluation framework is presented below.

A. Identification of the evaluation criteria.

The multiple criteria (or objectives), that are considered in the decision-making process for the decision-makers and experts, are identified.

B. Make pair-wise comparison and check consistency

The comparison in pairs of the elements of the criteria is realized. The comparison is realized based on Saaty's 1 - 9 fundamental scale. The value 1 indicates equal importance, 3 moderately more, 5 strongly more, 7 very strongly and 9 indicate extremely more importance. The values 2, 4, 6, 8 represent intermediate values of importance. The pair-wise comparison matrices are constructed. Consider the case of n criteria. A matrix $\mathbf{A} = (a_{ij})$ $1 \le i, j \le n$ is constructed. The entry a_{ij} represents a number in the Saaty's fundamental scale that shows how many times the criteria i is better than the criteria j. This matrix must satisfy the following properties cf. [15]:

- Reciprocity: if $a_{ij}=x$ then $a_{ji}=1/x$, with $x \in \{1/9;1/8;1/7;1/6;1/5;1/4;1/3;1/2;1;2;3;4;5;6;7;8;9\}$
- Homogeneity: if the elements i and j are considered to be equally important, then: $a_{ij}=a_{ji}=1$ and $a_{ii}=1$ for all i.
- Consistency: $a_{ik} \times a_{kj} = a_{ij}$ is satisfied for all $1 \le i,j,k \le n$.

From the property of reciprocity, only *n(n-1)/2* comparisons are needed in order to build a matrix **A** with a dimension of *n* x *n*.

Homogeneity is crucial for comparing elements of the same class, or with similar characteristics. In the case of comparisons between pairs, homogeneity is expressed by values of 1 when comparing two elements with no clear importance of one over the other. In particular, all the elements in the diagonal are equal to 1.

A third property, namely consistency, should theoretically be desirable for matrix **A**. Consistency expresses the coherence that should (perhaps) exist between judgments about the elements of a matrix **A**. Since preferences are expressed in a subjective manner it is reasonable that some incoherence to exist. When dealing with intangibles, judgments are rarely consistent. One source of inconsistency may arise from ordinal intransitivity (*x* is preferred to *y* and *y* to *z*, but *z* is preferred to *x*). In the general case, **A** is not consistent, because only estimates of the pair-wise comparison values are known through numerical judgment. For most problems we can consider that estimates of these values by an expert are assumed to be small perturbations of the `right' values. If $\mathbf{w}=(w_i) i=1,2,\ldots,n$ is the vector of weights then the a_{ij} elements estimate the weights w_i/w_j. In the ideal case of total consistency, the principal eigenvalue λ_{max} is equal to n, i.e $\lambda_{max} = n$, the relations between the weights and the judgements will be given by $w_i/w_j = a_{ij}$ for $i,j=1,2,\ldots,n$.

It appears that the weight determination of criteria is more reliable when using pair-wise comparisons than obtaining them directly, because it is easier to make a comparison between two attributes than to make an overall weight assignment.

Within AHP, the inconsistency within a set of comparisons can be measured through a consistency index (*CI*). It can be demonstrated that $\lambda_{max} \geq n$, and the difference $\lambda_{max} - n$ is an indicator of the inconsistency of the matrix. Indeed, this difference is zero for a perfectly consistent matrix, while it takes on increasing values as inconsistency increases [14].

The Consistency Index (*CI*) is defined as:

$$CI = \frac{\lambda_{\max} - n}{n-1}$$

When this index is calculated for a randomly generated $n \times n$ matrix we obtain the value Random Index (*RI*). From these quantities, defines the Consistency Ratio (*CR*) as the quotient *CI/RI*. The value of this ratio should be less than 0.1 in order to validate the consistency of the matrix **A**. If the Consistency Ratio (*CR*) > 0.1 then repeat the pair-wise comparisons.

C. Calculate criteria weights

In the analytic hierarchy process (AHP) literature, the derivation of weight from the pair-wise comparisons has been investigated extensively. Usual calculating methods are sum method, geometric mean method, eigenvector method and least square method.

In our evaluation framework we consider the sum method for calculate the weight.

D. Decision matrix construction and alternatives ranking

The decision matrix is defined by expert. Its entries represent the performance values of each alternative with respect to each criterion. If we consider *m* alternatives $A_1, A_2, \ldots, A_m$ the decision matrix (alternatives and criteria) is $\mathbf{B}=(b_{ij}) i=1,2,\ldots,m,\ j=1,2,\ldots,n$. The elements of each column have the same measurement unit. The alternatives are evaluated for the distinct criteria using different measurement units and scales. To bring the elements of the decision matrix **B** to compatible units is used normalization. Normalization makes all the elements lie between 0 and 1. There are several methods applied for normalization of the decision matrix elements. The normalization proposed to be applied for our evaluation framework is the vector normalization. If C_j is a minimum criterion then the elements of the column *j* in the normalized matrix:

$\mathbf{R} = (r_{ij})\ i = 1,2,\ldots,m,\ j = 1,2,\ldots,n$ are:

$$r_{ij} = 1 - \frac{b_{ij}}{\sqrt{b_{1j}^2 + b_{2j}^2 + \ldots + b_{mj}^2}}\ i = 1,2,\ldots m,\ j = 1,2,\ldots n$$

If C_j is a maximum criterion then the elements of the column *j* in the normalized matrix:

$\mathbf{R} = (r_{ij})\ i = 1,2,\ldots,m,\ j = 1,2,\ldots,n$ are:

$$r_{ij} = \frac{b_{ij}}{\sqrt{b_{1j}^2 + b_{2j}^2 + \ldots + b_{mj}^2}}\ i = 1,2,\ldots m,\ j = 1,2,\ldots n$$

The alternatives ranking is based on Simple Additive Weighting (SAW) method. SAW is one of the simplest forms of multi-criteria analysis [5]. The score for a given component is calculated as a weighted sum of the scores of its subcomponents. The method of calculation gives scores over time relative to the best performance achieved by a particular fishery. It does not provide scores that can be meaningfully compared with another fishery.

For each alternative i=1,2,…,m are calculated:

$$c_i = \sum_{j-1}^{n} r_{ij} \times w_j$$

The components of the vector c=(c_1,c_2,…,c_m) indicate the rank of the alternatives.

3 Application for Evaluating the Performance of a Romanian Fish Farm

The development of the fisheries sector in Romania aims to ensure a balance between the stock size and the exploitation level, strengthening and developing the competitiveness of certain economically viable undertakings, stabilizing the fish market, improving fish products quality, and supporting the economic development of fish-dependent regions. Romania completed negotiations with EU in the area of fisheries in June 2001, accepting the entire “acquis communautaire” without requesting any derogation or transition periods. Romania is a member country of EU since 2007.

Fisheries have traditionally been managed by direct restrictions, including seasonal and area closures, minimum mesh size, and access limitations. In recent years, licensing and the individual quota system were introduced as effort-control measures, in order to bring the fishing effort more in line with the available resources. Licenses relate to a specific group of species or gear type, and usually delimit the fishing area.

In this section we shall study an application of the evaluation framework for a fish farm, called Malina, located near the villages Sendreni and Smardan, Galati County, Romania. The total fishery area consists of 131 ha out of which 127 ha are covered by water.

The criteria considered are:

C1 - Quantity of fish (for various species and classes);

C2 - Diversity (number of fish species and categories);

C3 - Weight at delivery (for various species and classes);

C4 - Commodity production

C5 - Number of employees

C6 - Profit or loss

The alternatives are the performance of the fish farm in each of the years from the period 2003 - 2009. The comparison in pairs of the criteria is realized. The matrix **A** is build. The results are presented in Table 1.

Table 1. The comparison in pairs for criteria

	C1	C2	C3	C4	C5	C6
C1	1.00	2.00	0.33	0.20	1.00	0.14
C2	0.50	1.00	0.33	0.20	1.00	0.14
C3	3.00	3.00	1.00	0.20	2.00	0.20
C4	5.00	5.00	5.00	1.00	2.00	0.20
C5	1.00	1.00	0.50	0.50	1.00	0.20
C6	7.00	7.00	5.00	5.00	5.00	1.00

The Consistency Ratio (*CR*) of the matrix **A** is equal to 0.0823. The value of this ratio is smaller than 0.1 and validates the consistency of the matrix **A** of comparison in pairs.

The criteria weights are calculated based on the AHP method and are presented in Figure 1.

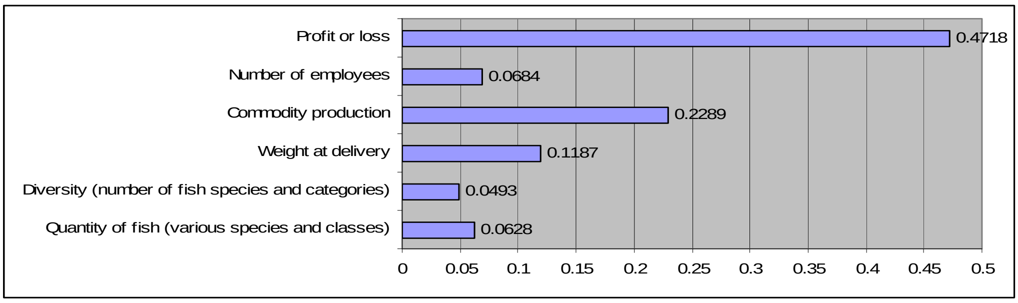

Figure 1. The computed weights of the criteria

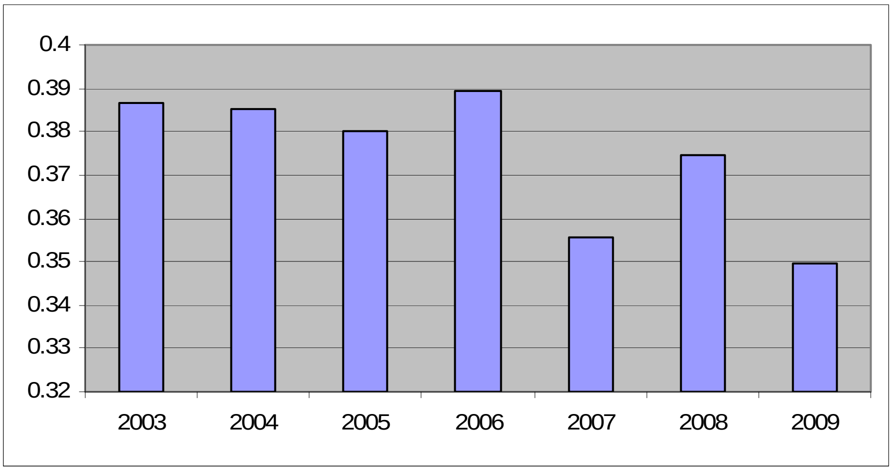

Figure 2. Ranking the performance of the fish farm Malina according the the SAW method

The ranks of the alternatives are determined by the SAW method. The criteria weights calculated, based on AHP method, are used in the SAW method. Each alternative, i.e. the fish farm performance, over the years 2003 – 2009, is evaluated according the above criteria. The matrix is normalized and the components c_i of the vector c are calculated. The components of the vector c=(c_1,c_2,…,c_m) indicate the rank of the alternatives. The results are presented in Figure 2.

4. CONCLUSION

In this paper we have presented a multi-criteria evaluation framework that incorporates two MCDA methods: the AHP method and the SAW method. The criteria weights are calculated by using the AHP. Afterwards rankings of the alternatives are determined by the SAW method. The model is used for the performance evaluation of Romanian fish farm called Malina over a period of seven years.

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REFERENCES

1. ANDREI, N., **On Quadratic Internal Model Principle in Mathematical Programming**, Studies in Informatics and Control, vol. 18,(4), 2009, pp 337-348.
2. ANDREI, N., **Open Problems in Nonlinear Conjugate Gradient Algorithms for Unconstrained Optimization**, Bulletin of the Malaysian Mathematical Sciences Society, 2011, in press.
3. CHARLES, A. T., **Sustainable Fishery Systems**, in Fish and Aquatic Resources Series, vol. 5, Blackwell Science, Oxford, 2001.
4. COELLO, C., **A Comprehensive Survey of Evolutionary-based Multiobjective Optimisation Technique**s. Knowledge and Information Systems: An International Journal 1, 1999, pp. 269-308.
5. JANSSEN, R., **Multiobjective Decision Support for Environmental Management**, Kluwer Academic Publishers, Dordrecht, 1992.
6. KALYANMOY, D., **Nonlinear Goal Programming using Multi-objective Genetic Algorithms**. Journal of the Operational Research Society 52, 2001, pp. 291-302.
7. LEUNG, P. S., J. MURAOKA, S. T. NAKAMOTO, S. POOLEY, **Evaluating Fisheries Management Options in Hawaii using Analytic Hierarchy**

Process (AHP). Fisheries Research 36 (2–3), 1998, pp.171-183.

8. MARDLE, S., S. PASCOE, I. HERRERO, **Management Objective Importance in Fisheries: An Evaluation using the Analytic Hierarchy Process (AHP)**. Environmental Management 33 (1), 2004, pp. 1-11.
9. NIELSEN, J. R., C. MATHIESEN, **Stakeholder Preferences for Danish Fisheries Management of Sandeel and Norway Pout**, Fisheries Research 77 (1), 2006, pp. 92-101.
10. RĂDULESCU, M., C. Z. RĂDULESCU, M. TUREK RAHOVEANU, G. ZBĂGANU, **A Portfolio Theory Approach to Fishery Management**, Studies in Informatics and Control, vol. 19(3), 2010, pp. 285-294.
11. ROMERO, C., T. REHMAN, **Multiple Criteria Analysis for Agricultural Decisions**, Second Edition, Volume 11 (Developments in Agricultural Economics) Elsevier, Amsterdam, 2003.
12. ROMERO C., **Risk Programming for Agricultural Resource Allocation: A Multidimensional Risk Approach**, Annals of Operations Research, 94, 2000, pp. 57-68.
13. SAATY, T. L., **The Analytic Hierarchy Process**, McGraw Hill Company, New York, 1980.
14. SAATY, T. L., **Decision Making with Dependence and Feedback: The Analytic Network Process**, 2nd edition, PRWS Publications, Pittsburgh, 2001.
15. SAATY, T.L., **Axiomatic Foundations of the Analytic Hierarchy Process**, Management Science, vol. 32(7) July 1986, pp. 841-855.
16. SOMA, K., **How to Involve Stakeholders in Fisheries Management – A Country Case Study in Trinidad and Tobago**. Marine Policy 27(1), 2003, pp. 47-58.
17. TANGOUR, F., P. BORNE, **Presentation of Some Metaheuristics for the Optimization of Complex Systems**, Studies in Informatics and Control, vol. 17(2), 2008, pp 169-180.
18. UTNE, I. B., **Are the Smallest Fishing Vessels the Most Sustainable? Trade-off Analysis of Sustainability Attributes**, Marine Policy 32(3), 2008, pp. 465-474.