Analytic Hierarchy Process in Selecting The Best Irrigation Method

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ABSTRACT

Selection of the best irrigation method for a given field conditions is a complex decision making problem. It is influenced by many factors such as crop density, growing conditions, water quality or topography, but it is also subject of judgments to be made by more or less experienced farmer or decision maker. In turn, consistent reasoning and a method of deriving solution (decision) by person(s) involved may become critical. A major issue of related decision process is how to manipulate decision factors efficiently and to assure consistency of the whole process, particularly of that part in which decision maker determines intensity of mutual dominance between factors. To handle a problem and trustworthy find the relative importance of objectives, sub objectives and alternatives with respect to stated overall goal, and all this in real field conditions, the Analytical Hierarchy Process (AHP) appears to be a good choice. In specific assessments described here AHP plays a role of efficient supporter to the decision maker in selecting the best irrigation method. Decision alternatives considered in the article are four methods of agricultural irrigation: border, furrow, sprinkler and trickle. They were mutually compared with respect to 7 criterions: crop density, sensibility to diseases, growing conditions, slope, infiltration rate, water quality and skills of labour. Brief description of AHP is followed by results of its application in selecting the best irrigation method. Comparison of AHP's results with results obtained by two other evaluating methods is also given.

Keywords: irrigation method, weight coefficient, decision making, hierarchy

INTRODUCTION

Making a decision to use irrigation and improve efficiency of agriculture is usually followed by next step -selection of the best irrigation method to be applied in real field conditions. This selection is influenced by different factors but primarily by investments, production expenses, expenses of irrigation system maintenance and irrigation system efficiency (Srdjevic, 1995). Crucial for making a decision are also real field conditions such as characteristics of the crop, water availability and quality, topology, soil characteristics, labour skills etc. (Holzapfel *et al*., 1985).

Criterions important in making a decision are generally very different and related to both qualitative and quantitative factors. To formulate criterions may also become a problem, because they should reflect more or less conflict farmer's interests such as increasing net return, reducing total cost of agricultural production, improving soil quality, reducting prices of agricultural products, improving usage of human resources and machines, optimizing water alocation etc. Therefore, systems approach appears necessary to be applied in order to help farmer to choose one irrigation method for specific situation in the field and to be determined that it is the best or at least the favourite one. The major issue is that systems approach could assure that important factors will be included and that evaluating technique will be applied properly, with assured consistency of the whole decision-making process as well.

In fact, the major issue is how to relate a variety of factors, i.e. to recognise their impacts and importance in real field conditions, and to determine dominance of one factor over another by investigating certain dominant/weak structures. Different weighting methods are used to create and manipulate ranks of objectives in multicriteria decision-making problems, to assign priorities or preferences of the decision maker while investigating possible alternative courses in strategic planning, or simply to allocate unit costs in transportation or transhipment problems. As far selection of an irrigation method is considered, it was Holzapfel *et al.* (1985) who initiated discussion by introducing an evaluating technique that can be denoted simply as the multiplicative equal importance method. He used that comparison method to select the best amongst 4 possible irrigation methods for certain field conditions. In continuation of this discussion, it was suggested by Srdjevic (1995, 1997) to use the additive weighting coefficient method instead. Srdjevic (1997) presented a rationale why the later method could be better in practice, particularly as far flexible decision making conditions are considered. Different approach, known as additive weighting coefficient method is introduced by Hashimoto (1980), and successfully applied in risk-related water resources systems planning (Hashimoto *et al.*, 1982). Modifications of this method made by Srdjevic (1987), and Srdjevic & Obradovic (1995) include grouping effect of differently ranked water users while assessing reliability-risk performance of complex water resources systems with reservoirs.

Selection of the best irrigation method is itself a multicriteria decision-making practice. Certain reasons, and particularly successful recent applications of the Analytic Hierarchy Process (AHP) (Saaty, 1980), indicate that AHP is suitablle to support such a practice. It was Alphonce (1997) who suggested that AHP has some potential in resolving certain decision problems in agriculture. Step forward was to recognize that its unique mathematical concept of deriving weighting coefficients for elements (criterions and alternatives) in hierarchies is interesting to compare with above mentioned weighting methods. Therefore AHP was applied to the same problem as before (Holzaphel *et al.*, 1980; Srdjevic, 1995; Srdjevic, 1997), and in this way a set of approaches to decision-making problems in agricultural irrigation was expanded.

As far AHP is considered, it should be noted that different techniques could yield different rankings of alternatives. This creates uncertainty about what method should be used and whether a particular technique is better suited to certain situations than others (Hajkowicz & Prato, 1998). Compared with five different models for estimating weight coefficients, AHP was found to produce the most credible results (Shoemaker & Waid, 1982). Pertinent literature also indicates that AHP is flexible decision making tool for solving complex multicriteria problems in diverse areas, particularly because it enables decomposition of given problem into hierarchy and assures that both qualitative and quantitative aspects of a problem are properly incorporated in evaluating process.

Herein it is presented how AHP may be used in selecting the best irrigation method. A set of 7 criterions with different metrics, and even without metrics (qualitative criterions), was identified and evaluated with respect to specified overall goal – the best irrigating method. Candidate set of irrigating methods included sprinkler, furrow, trickle and border. Those methods were considered as decision alternatives and then ranked by AHP, until the best one was identified.

ANALYTIC HIERARCHY PROCESS: A REVIEW

Analytic Hierarchy Process (AHP) is developed by Saaty (1980). The essence of the process is decomposition of a complex problem into a hierarchy with goal (objective) at the top of the hierarchy, criterions and sub-criterions at levels and sub-levels of the hierarchy, and decision alternatives at the bottom of the hierarchy – Fig. 1.

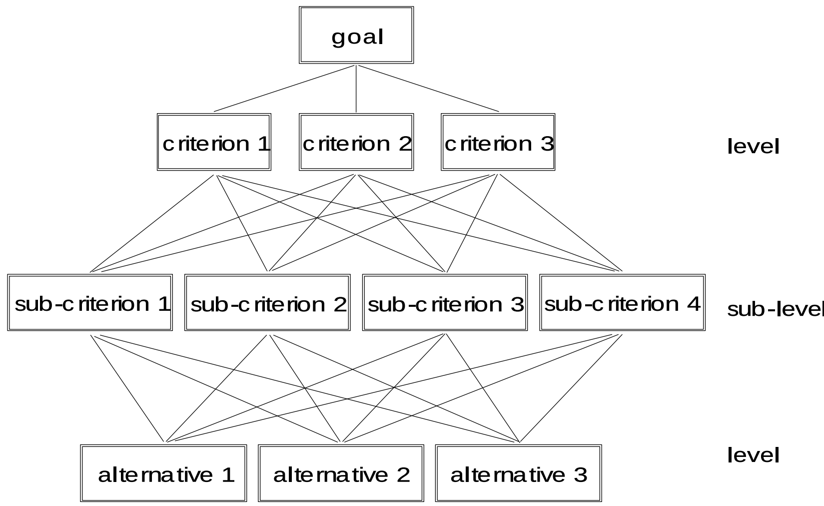

Fig. 1. Hierarchy in AHP.

Hierarchy does not have to be complete – element in higher level does not have to be a criterion for all elements of lower level. Hierarchy can also be divided into hierarchies that have only goal in common, but different criterions and even different alternatives.

After decomposing the problem into a hierarchy, elements at given hierarchy level are compared in pairs to assess their relative preference with respect to each of the elements at the next higher level. The verbal terms of the fundamental Saaty's scale presented in Table 1 are used to assess the intensity of preference between two elements. The ratio scale and the use of verbal comparisons facilitate the weighting of quantifiable and non-quantifiable elements. Once the verbal judgments are made, they are translated into numbers by means of the fundamental scale. This procedure is repeated for elements at each level in downward direction.

TABLE 1

The fundamental Saaty's scale for the comparative judgments

Num. values	**Verbal terms**	**Explanation**
1	Equally important	Two elements have equal importance regarding the element in higher level
3	Moderately more important	Experience or judgement slightly favours one element
5	Strongly more important	Experience or judgement strongly favours one element
7	Very strongly more important	Dominance of one element proved in practise
9	Extremely more important	The highest order dominance of one element over another
2, 4, 6, 8	Intermediate values	Compromise is needed.

The AHP is simple mathematical method based on elementary operations with matrices. It's strong background is, however, in rational treatment of hierarchical relations between different criterions (objectives) and alternatives which all may be understood as decision variables. By creating appropriate hierarchies, and by performing particular step-by-step procedure while creating comparison matrices at different hierarchical levels, AHP computes and aggregates their eigenvectors in straightforward manner until the composite final vector of weight coefficients for alternatives is computed. The entries of final weight coefficients vector reflect the relative importance (value) of each alternative with respect to the goal stated at the top of hierarchy. Decision maker may use this vector due to his particular needs and interests (Saaty, 1980; Alphonce, 1997).

To elicit pairwise comparisons performed at given level, a matrix A, is created in turn by putting the result of pairwise comparison of element i with element j into the position a_{ji} :

$$A = \begin{bmatrix} a_{11} & a_{12} & . & . & a_{1n} \\ a_{21} & a_{22} & . & . & a_{2n} \\ . & & & & . \\ . & & & & . \\ a_{n1} & a_{n2} & . & . & a_{nn} \end{bmatrix}$$

Reciprocal value of the comparison is placed in a position a_{ji}. If, for example, element 3 is strongly favoured if compared with element 2, the entry a_{32} should be set to 5, and a_{23} to as reciprocal value $1/5$.

The result of pairwise comparisons is weight coefficient for each element at given level, with respect to the element of a higher level. The weight coefficient of element is the measure of importance of the element for decision maker.

Weight vector, consisting of weight coefficients for elements at given level, could be obtained by using different techniques (Saaty, 1992). After obtaining weight vector, it is then multiplied with the weight coefficient of element at higher level (that was used as criterion for pairwise comparisons). Procedure is repeated upward for each level, until the top of the hierarchy is reached.

Overall weight coefficient, with respect to goal, for each decision alternative is then obtained. The alternative with the highest weight coefficient value should be taken as ‘the best alternative’.

One of the major advantages of AHP is that it calculates inconsistency index as a ratio of the decision maker’s inconsistency and randomly generated index (Saaty, 1980). This index is important for the decision maker to asure him that his judgements were consistent and that final decision is made well.

The value of inconsistency index lower than 0.10 is acceptable. Although higher value of inconsistency index requires re-evaluation of pairwise comparisons, decisions obtained in certain cases could also be taken as ‘the best alternative’ (Karlsson, 1998).

The major advantage of the AHP is that it helps decision maker to cope with a problem complexity by decomposing problem into a hierarchical structure. The weights of decision criteria and the priorities of alternatives are determined by comparing only two elements at the time. Both qualitative and quantitative elements of the hierarchy are allowed to be pairwise compared with ease. To express the intensity of preference of one element over the other, verbal terms, numeric scale or graphic bars may be used, as far interactive seanse at computer is undertaken. Finally, the analytic nature of AHP provides a clear rational for the choices that are being made. Its simplicity and intuitive logic facilitate the participation of various decision makers and even stimulate their involvement in brainstorming sessions which ultimatelly may improve collective thinking, reasoning, and the efficiency of group decision.

SELECTING IRRIGATION METHOD BY AHP

An example

Farmer wants to irrigate corn on the field that has slope of 1%. Soil of the field is sandy clay, with low infiltration rate. Quality of water that will be used for irrigating is good, and the labour skills are also good.

The criterions considered for making a decision are: crop density (**cropden**), sensibility to diseases (**disease**), growing conditions (**growcon**), slope (**slope**), infiltration rate (**infrate**), water quality (**watqual**) and skills of labour (**labskil**) – as suggested by (Holzapfel *et al.*, 1985). Decision alternatives are irrigating methods: furrow, border, sprinkler and trickle.

Figure 2 shows hierarchy for the farmer's decision problem. At the top of the hierarchy is goal – the best irrigation method. Criterions make the first level of a hierarchy, and the alternatives make second level.

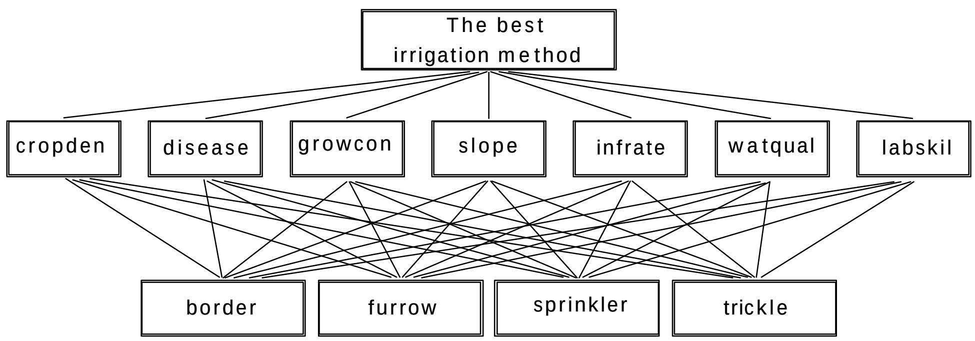

Fig 2. Hierarchy for the farmer's decision problem.

For choosing between different irrigation methods, farmer must weight and prioritize different criterions. That means he has not only to assign weights to each alternative, but also to assign weights to criterions related to the goal.

Following an initial step of AHP that consists of making a hierarchy, farmer has to compare in pairs all criterions with respect to goal by using Table 1, and to put results into the matrix of criterions. If farmer, for example, believes that crop density is moderately more important than infiltration rate, he will put number 3 in the position where row **cropden** crosses column **inf rate**, and number 1/3 in the position symmetrical with respect to main diagonal. Proceeding in the same manner he should make (7x6)/2=21 pairwise comparisons. Resulting matrix could look like this one:

	cropden	disease	growcon	slope	inf rate	watqual	labskil
cropden	1	5	1	2	3	4	6
disease	1/5	1	1/5	1/5	1/4	1/4	1/3
growcon	1	5	1	2	3	4	6
slope	1/2	5	1/2	1	3	2	4
inf rate	1/3	4	1/3	1/3	1	1/2	5
watqual	1/4	4	1/4	1/2	2	1	5
labskil	1/6	3	1/6	1/4	1/5	1/5	1

...(1)

Corresponding set of criteria weights is (Saaty, 1980): **cropden**–0.272, **disease**–0.032, **growcon**–0.272, **slope**–0.171, **infrate**–0.097,**watqual**–0.115, and **labskil**–0.042. Note that sum of all weights is equal to 1. Computed corresponding inconsistency index has the value of 0.07.

The next step of AHP is to compare alternatives with respect to each criterion. For example, with respect to crop density, farmer could create the following matrix of pairwise comparisons of alternatives:

$$\begin{matrix} \text{border} \\ \text{furrow} \\ \text{sprinkler} \\ \text{trickle} \end{matrix} = \begin{bmatrix} & \text{border} & \text{furrow} & \text{sprinkler} & \text{trickle} \\ & 1 & 3 & 1/5 & 4 \\ & 1/3 & 1 & 1/7 & 3 \\ & 5 & 7 & 1 & 9 \\ & 1/4 & 1/3 & 1/9 & 1 \end{bmatrix}. \qquad \text{(for } \textbf{cropden} \text{ criterion)} \qquad \ldots(2)$$

Corresponding set of weights for alternatives is: **border**–0.195, **furrow**–0.097, **sprinkler**–0.660, and **trickle**–0.049, and again sum of weights is 1.

After similar comparisons of alternatives with respect to all criterions are completed, the following matrix is created:

$$\begin{matrix} \text{border} \\ \text{furrow} \\ \text{sprinkler} \\ \text{trickle} \end{matrix} = \begin{bmatrix} \text{cropden} & \text{disease} & \text{growcon} & \text{slope} & \text{inf rate} & \text{watqual} & \text{labskil} \\ 0.195 & 0.211 & 0.163 & 0.095 & 0.125 & 0.354 & 0.078 \\ 0.097 & 0.368 & 0.395 & 0.160 & 0.222 & 0.131 & 0.125 \\ 0.660 & 0.054 & 0.047 & 0.277 & 0.077 & 0.161 & 0.306 \\ 0.049 & 0.368 & 0.395 & 0.467 & 0.577 & 0.354 & 0.492 \end{bmatrix} \qquad \ldots(3)$$

The final step consists of creating a linear combination of products of criteria weights and corresponding collumns in (3):

$$\begin{matrix} \text{border} \\ \text{furrow} \\ \text{sprinkler} \\ \text{trickle} \end{matrix} = 0.272 \begin{bmatrix} 0.195 \\ 0.097 \\ 0.660 \\ 0.049 \end{bmatrix} + 0.032 \begin{bmatrix} 0.211 \\ 0.368 \\ 0.054 \\ 0.368 \end{bmatrix} + 0.272 \begin{bmatrix} 0.163 \\ 0.395 \\ 0.047 \\ 0.395 \end{bmatrix} + 0.171 \begin{bmatrix} 0.095 \\ 0.160 \\ 0.277 \\ 0.467 \end{bmatrix} + $$
$$+ 0.097 \begin{bmatrix} 0.125 \\ 0.222 \\ 0.077 \\ 0.577 \end{bmatrix} + 0.115 \begin{bmatrix} 0.354 \\ 0.131 \\ 0.161 \\ 0.354 \end{bmatrix} + 0.042 \begin{bmatrix} 0.078 \\ 0.125 \\ 0.306 \\ 0.492 \end{bmatrix} \qquad \ldots(4)$$

and computing so-called composite weight vector for alternatives:

$$\begin{matrix} \text{border} \\ \text{furrow} \\ \text{sprinkler} \\ \text{trickle} \end{matrix} = \begin{bmatrix} 0.182 \\ 0.231 \\ 0.235 \\ 0.351 \end{bmatrix} \qquad \ldots(5)$$

The decision alternative with the highest composite weight coefficient here is trickle – 0.351, so this one should be chosen by farmer as the best irrigation method for given field conditions.

Since computed the overall inconsistency index was equal to 0.05 (lower than 0.10), selection of the best irrigation method by AHP could be accepted as completed.

A discussion

For computing global acceptability of particular irrigation method, Holzapfel *et al.* (1985) proposed the relation:

$$\mathrm{VIM}_j{}^m = \prod_{i=1}^{N} \left(\frac{(\mathrm{I}_i)_j}{100} \right) \quad \ldots (6)$$

where VIM_j is the relative global value of the j-th irrigation method and I_i is the index of its acceptability/adaptability related to i-th field parameter. N is the number of field parameters analyzed (i.e. indices used). Superscript m simply indicates multiplicative type of relation (6). Due to Holzapfel *et al.* (1985), VIM may range from 0 to 1. Zero final value of VIM should mean that particular irrigation method is not suitable for specified field conditions, and the opposite conclusion should stand for VIM equal to 1.

The underlying assumption in deriving relation (6) was that indices I_1 through I_N are of an equal importance within ranking procedure. Starting from that point, an alternative approach for computing VIM is proposed by Srdjevic (1996). A major difference made is that above mentioned assumption is not valid any more. On the contrary, indices are assumed not to have the same mutual (relative) importance to the decision maker (farmer). This means that while analyzing particular field and crop conditions and constraints one should rank indices before multiplication (6) is performed and weight them appropriately. In this way one may define preferences among indices and build in so-called intentional strategy into decision-making process. Srdjevic (1996) suggests that in preparing an appropriate weighting coefficient scheme it is enough to define preference list of indices and associate them to priority numbers appropriately.

If priority number z=1 is associated with the highest priority (most important) index, and z=N with the lowest priority (least significant) one, corresponding weight coefficients may simply be defined as reciprocals: $w_1=1/z_1$, ..., $w_N=1/z_N$, and weighted relative value of the j-th irrigation method could be computed as:

$$\mathrm{VIM}_j{}^w = \left(\sum_{i=1}^{N} \left[(\mathrm{I}_i)_j / 100 \right] w_i \right) / \left(\sum_{i=1}^{N} w_i \right) \quad \ldots (7)$$

Superscript w here indicates ‘weighting type’ of relation, and w_i is the weighting coefficient for i-th index; other symbols have the same meanings as before.

To compare some of the results, let us recall that irrigation methods used here as decision alternatives are the same as those used by Holzaphel *et al.* (1985) and Srdjevic (1996). In these earlier works, 7 to 9 indices of acceptability/adaptability of irrigation methods to certain field parameters are used. Herein, a set of 7 field parameters is used as a criterion set. In all three cases the same crop (corn) is taken as an example, and similar field conditions (crop density, infiltration rate, slope of the terrain, etc.) are assumed. In all three cases the overall goal was the same – to select the best irrigation method.

As an illustration, Table 2 presents the main results obtained by using relations (6) and (7), and by using AHP. According to the Table 2, two weighting methods – relation (7) and AHP – identify trickle as the best irrigation method for given field and crop conditions. Relation (6) puts a furrow method at the top and trickle method to the second place. Weighting method (7) puts furrow irrigation to the second place, while AHP ranks it as the third, and sprinkler irrigation validates as the second best method (after trickle).

TABLE 2
Ranking of irrigation methods by three methods

Irrigation method	**VIM** ^{m} **Rel. 6**	**VIM** ^{w} **Rel. 7**	**AHP**
Sprinkler	0.153 (**3**)	0.737 (**4**)	0.235 (**2**)
Border	0.098 (**4**)	0.771 (**3**)	0.182 (**4**)
Furrow	0.238 (**1**)	0.847 (**2**)	0.231 (**3**)
Trickle	0.206 (**2**)	0.928 (**1**)	0.351 (**1**)

CONCLUSION

Analytic Hierarchy Process is recognized as a highly competitive tool to the other decision-making tools (Karlsson, 1998; Alphonce, 1997; Narasimhan, 1983). Major advantages of AHP are (Narasimhan, 1983):

1. It formalizes and renders systematic what is largely a subjective decision process, and as a result facilitates ‘accurate’ judgments;
2. Weights of criterions are also provided to decision maker;
3. Sensitivity analysis is easy to conduct by using computer.

One of the most important advantages of the method is that AHP provides to the decision maker the measure of his inconsistency while reasoning and comparing elementsd within the hierarchy of a problem. This fact is of great significance for real life applications, i.e. when resolving complex multicriteria and multiatribute problems.

Some of those AHP’s advantages are recognized in decision-making experiment described here. For given field conditions and with respect to 7 selected criterions (crop density, sensibility to diseases, growing conditions, slope, infiltration rate, water quality and skills of labour), one of four possible alternative irrigation methods (furrow, border, trickle and sprinkler) is selected by AHP as the best. It was trickle method which appeared to be the best alternative.

When put in a competitive environment created by other evaluating methods, results derived by AHP method appear to be thrustworthly in both (1) computed relative values of irrigation methods with respect to the goal, and (2) computed low inconsistency index for the whole decision making process performed.

ACKNOWLEDGEMENT

Authors would like to thank The Expert Choice Inc., Pittsburgh, USA for providing temporal license for software EC Pro (Expert Choice Professional) used in research and partially described in this paper.

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