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MULTICRITERIA OPTIMIZATION OF AN IRRIGATION SYSTEM

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Abstract. *The multicriteria optimization of an irrigation system is presented. The emphasis is on designing alternative systems and defining optimization criteria. Multicriteria optimization of the irrigation system "Leskovacko polje" is performed by the Compromise Ranking Method.*

Key words: *Irrigation system, Alternatives, Multicriteria, Ranking*

1. INTRODUCTION

The drought has caused the damage in Serbia in 1994, which is estimated to one billion dollars. There is a chance that the drought may occur again in the next year. Many analysis indicate the importance of irrigation which should enable the agricultural production.

Total surface of irrigation systems in central Serbia is 25800 ha (3% of land suitable for irrigation). But, small number of existing systems are used. Only 5000 ha are irrigated, i.e. less than 20% of surfaces within the systems.

There are many reasons for this situation. One of them is the former practice in system design, where one or few alternatives were proposed, and a decision maker, based on his estimation, has chose an alternative. This estimation is made subjectively. Sometimes a decision is based on economic criterion, neglecting technical, social and other aspects of system. The consequences of this approach are evident, the systems are not in operation, although they were designed as an optimum solution according to an criterion.

This situation shows a need for multicriteria optimization, which includes all or at

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least main effects of the system. Multicriteria optimization enables an analysis of system parameters, and optimum solution determination based on all criteria. The criteria are conflicting and an optimum solution should represent a compromise of different interests.

2. CRITERIA AND EVALUATION OF ALTERNATIVES

When "optimum solution" is considered, it is necessary to relates "optimum" with criterion for evaluation and selection. The criteria for optimization could be[3]: economic, expressed by monetary units (investment costs, operation costs), time efficiency (duration of system construction), probabilistic efficiency (reliability) and quantitative efficiency (quanitities of supplied water, changes of water regimes, indexes of water quality).

The following criteria are adopted optimization of an irrigation system :

f_1 investment costs (DM/ha),
f_2 operation costs (DM/ha),
f_3 duration of system construction (years),
f_4 quantitative deficit of water (%),
f_5 deficit duration (days),
f_6 water resources influence of system,
f_7 social impact,
f_8 median diameter (mm),
f_9 water quality for irrigation,

These criteria could be grouped as: economic (f_1,f_2), time (f_3), water resources (f_4, f_5), system impact (f_6, f_7) and irrigation (f_8, f_9).

Investment costs should be determine with established prices. The all constituent elements of realization are included in price analysis. The investment costs include: costs of sprinkler, pipes, wheels, links and other equipment.

Operation costs include: labour, electrical energy and fuel, amortization, insurance, maintenance and other expenditures related to the system operation.

Investor and users of the system have interest for short-time period of system construction. Shortening of construction time should be with a respect to technical and economical conditions.

The basic task of irrigation system is water supply of plant on time. Water source should daily supply enough quantity of water, if not, there will be two types of water deficit: quantitative and timely. If water source is a river, deficits are determined by a methodology developed in [7]. When water source is reservoir, then HEC-5 program [4] could be used. Deficit is expressed in % or m^3 (quantitative deficit), and in days (time deficit).

Irrigation as a water consumer has the great influence on water balances, and it is in conflict with other water resources purposes. For example, if the water is taken from a multipurpose reservoir above hydroelectric power station, the fall and water should be lost for the energy purpose [1]. Also, the water is used for irrigation in summer when the electrical energy consumption is reduced.

Water resources systems have an important social impact. Successful solved "water" problems contribute to the development of society. Social study for irrigation system project should include the following data : number of pure agricultural farms, number of mixed family labour, economic standard, technical equipment, location and size of property.

Also, the following aspects are taken into consideration in analyzing the social inpact of system: demographic, migration, living standards, unemployment, health, social security, recreation.

Mediana diameter (dmed) was included as an objective index of rain fineness. This is a diameter of drop determining that 50% of total water is sprinkled on land in a form of drops with diameter smaller than dmed [5]. In all tested sprinklers, mediana diameter decreases if pressure increases, and it increases if distance from sprinkler increases. More fineness rain means less land damages. A fact that periphery receives rain with larger drops with all tested pressures, it is important for practice. Larger drops cause compression of surface soil layer in decreasing porosity of this layer.

Water quality is important in irrigation. Over 20% of all irrigated surfaces in the world are deterioarated by salinity. Water quality is estimated by the chart USSL [2] using of J.M. Servante' s classification in the range 1-7. The mark 7 is given for good water quality for irrigation and it corresponds to the class C1-S1. The mark 1 is given to the water that can not be used for irrigation (class C4-S4).

3. MULTICRITERIA RANKING METHOD: VIKOR

Program package VIKOR is developed for multicriteria ranking of alternatives by Compromise Ranking Method. It starts from expression of measures Sj and Rj for alternative aj

$$S_j = \sum_{i=1}^{n} \omega_i (f_i^* - f_{ij}) / (f_i^* - f_i^-) \quad (1)$$

$$R_j = \max_i [\omega_i (f_i^* - f_{ij}) / (f_i^* - f_i^-)] \quad (2)$$

$$f_i^* = \max f_{ij}, \quad f_i^- = \min f_{ij} \quad (3)$$

ω_i - weigth of i - criterion function

Measure for multicriterion ranking method VIKOR is:

$$Q_j = vQS_j + (1 - v)QR_j \quad (4)$$

where:

$$QS_j = (S_j - S^*) / (S^- - S^*) \quad (5)$$

$$QR_j = (R_j - R^*) / (R^- - R^*) \quad (6)$$

$$S^* = \min S_j, \quad R^* = \min R_j \quad (7)$$

$$S^- = \max S_j, \quad R^* = \max R_j \quad (8)$$

v - weight of decision - making strategy by "criteria majority".

Alternative a_j is better than a_k, ranked by Q, if $Q_j < Q_k$ and has higher position on ranking list. Compromise ranking list for given v is obtained by ranking with Q measure [6].

Results of VIKOR are ranking lists for different values of parameter v. In this case study the values of parameter *v* chosen are 0, 0.5 and 1. Stability of alternatives position on ranking list should be analyzed by various criteria weights.

4. EXAMPLE

The irrigation system "Leskovačko polje" is an illustrative example. The parameters for alternatives determination are: water source (Juzna Morava river, Barje reservoir), location of water capture (upstream and downstream of mouth of Vlasina river) and equipment for irrigation (wheel-line devices, TYPHON , BOOM). The following alternatives are defined :

JMu Alternative. Water is taken from Juzna Morava river, upstream from Vlasina mounth. Main canal passes through the field and eventual water excess is let into the Veternica river. There are 12 pump stations on a canal for water lifting into the pipelines. Wheel-line devices are connected on hydrants of distribution network. Pressure in network is 3-4 bar. Surface of subunit is 27 ha .

JMd Alternative is with pump stations on a riverbank of Juzna Morava, down-stream of Vlasina mouth. Wheel-line devices are connected on hydrants of distribution network. Pressure in network is 3-4 bar. Surface of subunit is 27 ha.

Vet1 Alternative. Water is released from Barje reservoir into the Veternica river. Pump station is on the riverbank and it lifts water into pipelines. Wheel-line devices are connected on the hydrants of distribution network. Pressure in network is 3-4 bar.

Vet2 Alternative. Water source is as in Vet1. TYPHON devices are connected on hydrants of distribution network. Devices work under high pressure (4-7 bar) and they irrigate 0.81 ha from one position. Surface of subunit is 25.4 ha.

Vet3 Alternative. Water source is asin Vet1. BOOM devices are connected on hydrants of distribution network. Devices work under high pressure (6 - 9 bar) and they irrigate 1.82 ha from one position. Surface of subunit is 21.8 ha.

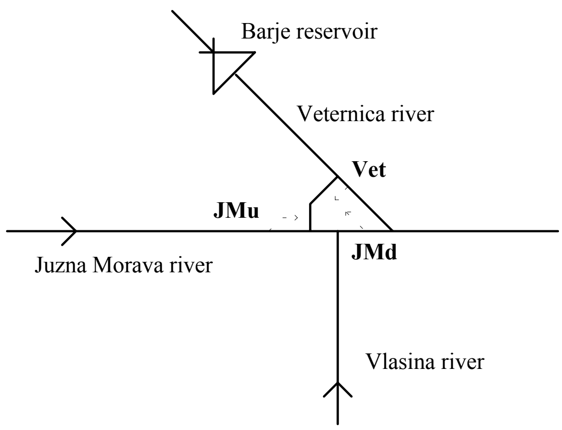

Fig. 1 The system "Leskovačko polje"

Values of criterion functions are determined for all alternatives (Table 1).

Table 1. Values of criterion functions for five alternatives

alternatives	**JMu**	**JMd**	**Vet1**	**Vet2**	**Vet3**
f_1 (DM/ha)	4760	5347	8872	9817	9444
f_2 (DM/ha)	728	816	942	1033	976
f_3 (years)	2	2	3	3	3
f_4 (% deficit)	6	2.5	0	0	0
f_5 (days)	2	1	0	0	0
f_6	3	3	5	5	5
f_7	4	5	2	2	2
f_8 (mm)	1.13	1.13	1.13	1.26	1.13
f_9	5	6	5	5	5

The multicriteria ranking lists are obtained by VIKOR program package with different criteria weights (Table 2).

Table 2. Compromise solutions from several rank lists

rang	**EQ**	**ECON**	**WAT**	**IMP**	**MEL**
I	**JMd**	**JMd**	**JMd**	**JMd**	**JMd**
II		**JMu**			

First ranking list (**EQ**) was obtained without priority to any of criteria, i.e. $\omega_i = 1.0$. VIKOR method proposes **JMd** alternative as a compromise solution (for given weights ω_i). Second ranking list (**ECON**) was obtained with criteria weights $\omega_1 = \omega_2 = 1.5$, and others were equal to one, $\omega_i = 1.0$; the importance was to lower investment and operation costs. **JMd** and **JMu** alternatives are a set of compromise solutions. Third ranking list (**WAT**) was obtained by the following combination of criteria weights $\omega_6 = \omega_7 = 1.2$, and others were equal to one, $\omega_i = 1.0$; the importance was given to water resources criteria. VIKOR method proposes **JMu** alternative as a compromise solution. Fourth ranking list (**IMP**) was obtained for criteria weights $\omega_6 = \omega_7 = 1.2$, and the others were equal to one, $\omega_i = 1.0$; the importance was given to system impact. **JMd** alternative is a compromise solution. Fifth rank list (**MEL**) was obtained for criteria weights of $\omega_8 = 1.2$ and $\omega_9 = 1.4$, and the others were equal to one, $\omega_i = 1.0$; the importance was given to a group of melioration criteria. **JMd** alternative is a compromise solution.

Alternative **JMd** is proposed as a compromise solution to the decision maker. Water for irrigation will be from the Juzna Morava river downstream from mouth of the Vlasina river. In the watershed of the Vlasina river there are no industrial plants so that the water is of the best quality.

5. Conclusion

The irrigation system could be evaluated with several criteria functions (economic,

engineering, social, environmental). The alternatives are generated with different values of system parameters (location of water source, equipment dimension). Alternatives are ranked and compromise solution is obtained by the Compromise Ranking Method (VIKOR). The preference of the decision maker is expressed by the criteria weights.

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VIŠEKRITERIJUMSKO RANGIRANJE VARIJANTI SISTEMA ZA NAVODNJAVANJE

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U radu je prikazan postupak višekriterijumske optimizacije sistema za navodnjavanje. Težište se stavlja na izbor kriterijuma za vrednovanje i optimizaciju varijanti sistema. Primenom metode "VIšekriterijumsko KOmpromisno Rangiranje" (VIKOR) izvršena je višekriterijumska optimizacija sistema za navodnjavanje "Leskovačko polje". Dobijeni rezultati potvrdjuju ispravnost i upotrebljivost postupka za višekriterijumsko rangiranje.

Ključne reči : *sistem za navodnjavanje, varijante, višekriterijumsko rangiranje*