Study on Measurement and Evaluation of Performance of Farmer-Managed Irrigation Systems in China

Mao Zhi[47]

ABSTRACT

IN CHINA, ABOUT one half of the total irrigated farmland in the country is completely managed by the farmers themselves. Moreover, all the irrigation systems under branch canals in China are managed by the farmers. There is therefore an urgent need to study methods of measurement and evaluation of performance of Farmer-Managed Irrigation Systems (FMIS) in order to improve the performance and raise the management level of Chinese FMIS. This paper proposes a method of quantitative evaluation of FMIS performance, by scoring according to an index system consisting of sixteen techno-economical factors. The methods of measurement and calculating the mark of each index and the weighted average mark (WAM) and evaluating the FMIS performance on the basis of the WAM are presented. Finally, based on the results of the application of the abovementioned methods in a typical FMIS in South China, the methods of measurement and calculation of each index and the WAM, and the method of evaluating FMIS performance are illustrated.

INTRODUCTION

In China, small-scale irrigation systems which irrigate areas of less than 667 hectares (ha), or whose total reservoir capacity, as the main water source is less than one million m^3, are managed by the farmers themselves and are thus farmer-managed irrigation systems (FMIS). Large-scale and medium-scale systems are managed by government agencies (GMIS). According to the official statistics in 1990, the total irrigated farmland in China is 48 million ha. About half of this area is controlled by FMIS. Moreover, the management responsibility of government agencies in GMIS is limited to managing the main and branch canals and the major facilities, while most of the activities connected with the lower-level canals and field channels are carried out by farmers themselves. Accordingly, all the irrigation systems in China below the branch canals, may be considered FMIS. Therefore, studies to improve the performance of FMIS in China are an urgent need in order to conserve irrigation water and increase crop yields.

To better understand present performance and problems and to develop a plan for improving FMIS performance, research on performance measurement and evaluation have already begun and a method for evaluating the performance has been tested in some typical FMIS in South China.

47 Professor of Irrigation and Drainage Engineering, Wuhan University of Hydraulic and Electric Engineering, Wuhan, Hubei Province, 430072, People's Republic of China.

Based on an analysis of the results of the research and experiments in a typical FMIS in South China by the author, and in light of the special characteristics of FMIS, a method of quantitative measurement and evaluation of performance by scoring and calculating the weighted average mark (WAM) has been developed. The method and its application are described and discussed below.

AN INDEX SYSTEM FOR EVALUATING FMIS PERFORMANCE AND FOR THE MEASUREMENT AND CALCULATION OF THE INDICES

According to the national unified index system (on trial, 1982) and in light of the specific conditions of FMIS in South China, the following index system is used. It consists of sixteen techno-economical indices for analyzing the performance of FMIS, organized into four groups. The methods of measurement and calculation of the indices are as follows:

(1) **Group 1. Indices of irrigation water utilization**

The four indices used are

1) Efficiency of irrigation water supply, S, (%).

$$S = \frac{W}{W_r} * 100$$

where W and W_r are the actual and required annual quantity of irrigation water diverted from the water sources in the same years (m^3/year). W can be obtained by measuring the discharge from headworks of the various water sources. W_r can be calculated using the water balance method, in which the crop water requirements may be obtained from the irrigation experimental station in the vicinity or from a nearby region, or may be read from the provincial maps of isolines of crop water requirements and water quotas, which have been prepared for most provinces in China.

2) Efficiency of utilizing local water resources within the irrigation district, U, (%)

$$U = \frac{Ww}{Wwr} * 100$$

where W_w and W_{wr} are the actual and required (in the same hydrologic years) annual quantity of irrigation water supply from the water sources within the irrigation district (m^3/year).

3) Irrigation application efficiency, E.

$$E = \frac{W_f}{W}$$

where W_f is the total quantity of irrigation water delivered to the fields (m^3/year); E can be calculated by:

$$E = \overset{n}{\underset{i=1}{\pi}} E_i * E_f$$

where E_1 is the application efficiency of irrigation canals of i-th rank, n is the total numbers of ranks of canals, E_i is calculated from the water loss in irrigation canals, which can be measured either by the static or dynamic test methods in one or two typical canals of each rank; E_f is the water application efficiency in the field. In South China, for rice fields, $E_f = 1$.

4) Gross annual irrigation water quota, M, (m^3/ha/year) and the percentage of standard irrigation quota, P_m, (%)

$$M = \frac{W}{A}$$

$$P_m = \frac{M * E + 300}{M_n + 300} * 100$$

where A is the actual irrigated area in ha; M_n is the standard net annual irrigation water quota (m^3/ha/year). This can be obtained from irrigation experimental stations or read from the provincial maps of isolines of irrigation water quotas.

(2) Group 2. Indices of irrigation area and engineering aspects of the system

Three indices are used:

5) Percentage of actual irrigated area, F, (%)

$$F = \frac{A}{Ap} * 100$$

where A_p is the planned irrigated area in ha in the same year.

6) Percentage of area provided with field irrigation and drainage systems, D, (%)

$$D = \frac{A_f}{A_{fd}} * 100$$

where A_f and A_{fd} are the actual and design area provided with the field irrigation and drainage systems (ha).

7) Percentage of facilities in good condition, G, (%)

$$G = \frac{N_g}{N}$$

where N is the total number of facilities for irrigation or drainage in a particular category; N_g is the number of the facilities in good condition (safe, integrated, functioning normally and attaining the design standard).

(3) **Group 3. Indices of yield and economic benefit**

The six indices used are

8) Yield per unit area, Y, (t/ha/year) (t=ton) and the percentage of the highest yield per unit area, P_ya, (%).

$$Y_a = \frac{Y}{A}$$

$$P_ya = \frac{Y_a}{Y_ah} * 100$$

where Y is the total annual yield (t/year) of crops in A (ha); Yah is the historical highest annual yield per unit area (t/ha/year).

9) Yield per unit quantity of irrigation water, Y_w, (t/m^3) and the percentage of the highest yield per unit quantity of irrigation water, P_yw, (%).

$$Y_w = \frac{Y}{W}$$

$$P_{yw} = \frac{Y_w}{Y_{wh}} * 100$$

where Y_{wh} is the historical highest annual yield per unit quantity of irrigation water (t/m^3).

10) Percentage of the highest total yield, P_y, (%)

$$P_y = \frac{Y}{Y_h} * 100$$

where Y_h is the historical highest total annual yield in the whole irrigation district (t/year).

11) Efficiency of collection of irrigation water charges, P_i, (%)

$$P_i = \frac{lw}{lwr} * 100$$

where lw and lwr are the actual and required total annual income from irrigation water charges in the whole irrigation district (yuan/year) (Yuan is the Chinese unit of currency. In 1991, one yuan = US$0.192); lw should be calculated on the basis of the collection of water charges from the total irrigated area and using the unified price of water which is set by the local government.

12) Irrigation benefit per unit area, b, (yuan/ha/year) and percentage of the highest benefit, P_B, (%)

$$b = (y - y_o)c + (y' - y_o')\,c' - h'$$

$$P_B = \frac{b * A}{B_h' * 100}$$

where y and y_o are the annual yields of crops per unit area (t/ha/year) with and without irrigation, respectively; y' and y_o are the annual quantities of by-products per unit area with and without irrigation (t/ha/year); c and c' are the costs of agricultural product and by-product (yuan/t); h is annual expenditure per unit area for irrigation (yuan/ha/year); B_h is the historical highest total annual irrigation benefit in the whole irrigation district (yuan/year).

13) Percentage of financial self-sufficiency, B, (%)

$$B = \frac{I}{H} * 100$$

where I is the total annual income of the FMIS, which is obtained from water charge and several other revenue (yuan/year); H is the total annual expenditures for irrigation management which includes the current expenditures and the payment to the peasant managerial personnel and irrigators (yuan/year).

(4) Group 4. Indices of land melioration and environmental impact

Three indices are used:

14) Rate of change of groundwater table, R, (%)

$$R = \frac{D_1 - D_t}{D} * 100$$

where D_1 and D_t are the annual average depth of groundwater table last year and this year (m); D is the mean annual depth of groundwater table (m).

15) Percentage of the melioration of low-yield land, Z, (%)

$$Z = \frac{A_{Lm}}{A_L} * 100$$

where A_L is the total area of original low-yield land in which the crop yields are lower than one fourth of normal yields (ha); A_{Lm} is the area of low-yield land which has been improved by measures of drainage and irrigation, and the crop yields have been raised over one half of the normal yields (ha).

If there is no low-yield land ($A_1 = 0$) in this irrigated district, $Z = 90$.

16) Percentage of afforestation of canals, J, (%)

$$J = \frac{L_t}{L} * 100$$

where L is the total length of conveyance canals (km)); L_t is the length of conveyance canals along which the trees have been planted (km).

CALCULATION OF THE WAM OF THE INDEX SYSTEM

The performance of FMIS can be quantitatively evaluated by the weighted average mark (WAM) of index system. The higher the WAM, the better the performance. The basis for calculating WAM is the values of mark and the weight of each index. The methods for determining these values will be introduced in the following:

Determination of the Mark and Weight of Each Index

Based on the results of application of the WAM method to evaluate the performance of some typical FMIS in South China and the suggestions of the peasant personnel, the methods for determining the mark and weight of each index are as given in Table 1.

Method of Calculating the Weighted Average Mark of the Index System

For a given FMIS, the WAM is calculated by

$$WAM \ \sum_{i=i}^{16} (ID_i * WT_i) + \blacktriangle MK_1 + \blacktriangle MK_2 + \blacktriangle MK_3 + \blacktriangle MK^1$$

where ID_i and WT_i are the values of i-th index and its weight; $\blacktriangle MK_1$, $\blacktriangle MK_2$ and $\blacktriangle MK_3$ are the additional marks. If the management organization is sound and the great majority of peasant management personnel have been trained properly,

$$\blacktriangle MK_1 = 4$$

If the records, tables and charts of management are complete,

$$\blacktriangle MK_2 = 2$$

If the advanced technique has been applied and proved to be effective,

$$\blacktriangle MK_3 = 4$$

If it does not accord with the above respective demands, $\blacktriangle MK_1$, $\blacktriangle MK_2$ and $\blacktriangle MK_3$ are equal to zero.

Table 1. Methods of calculating the marks and weights of indices.

No.	Names, symbols and units of indices	Methods of calculating mark (*MK*=mark)	Values of weight (WT=weight)	
1	Efficiency of irrigation water supply, *S*, (%)	$MK=S$	0.03	0.20
2	Efficiency of utilizing local water resource within the irrigation district, *U*, (%)	$MK=U$	0.06	
3	Irrigation application efficiency, *E*	$MK=100E * K$ $K=1.3$ ($A<200$ ha) $K=1.4$ ($A=200 \sim 1000$ ha) $K=1.5$ ($A>1000$ ha)	0.08	
4	Percentage of standard irrigation water quota, P_m, (%)	$MK=50+0.5P_m$ ($P_m \leq 100$) $MK=150-0.5P_m$ ($P_m>100$)	0.03	
5	Percentage of actual irrigated area, *F*, (%)	$MK=2F-100$	0.08	0.20
6	Percentage of area provided with field irrigation and drainage systems, *D*, (%)	$MK=D$	0.04	
7	Percentage of facilities in good condition, *G*, (%)	$MK=2G-100$	0.08	
8	Percentage of the highest yield per unit area, P_{ya}, (%)	$MK=2P_{ya}-100$	0.05	0.35
9	Percentage of the highest yield per unit quantity of irrigation water, P_{yw}, (%)	$MK=2P_{yw}-100$	0.05	
10	Percentage of the highest total yield, P_y, (%)	$MK=2P_y-100$	0.10	
11	Efficiency of collection of irrigation water charges, P_1	$MK=P_1$	0.05	
12	Percentage of the highest benefit, P_B, (%)	$MK=P_B$	0.05	
13	Percentage of financial self-sufficiency, *B*, (%)	$MK=B$ ($B \leq 100$) $MK=100$ ($B>100$)	0.05	
14	Rate of change of groundwater table, *R*, (%)	$MK=2.5\,(40-\lvert R \rvert)$	0.05	0.15
15	Percentage of the melioration of low-yield land, *Z*, (%)	$MK=Z$ ($A_L>0$) $MK=90$ ($A_L=0$)	0.08	
16	Percentage of afforestation of canals, *J*, (%)	$MR=J$	0.02	

▲MK' is the deduction of marks due to an accident arising from the negligence of management personnel. The values of ▲MK' are as follows:

For ordinary accident:

▲$MK' = 2.0$	(A <100 ha)
▲$MK' = 1.5$	(A = 100 ~ 1000 ha)
▲$MK' = 1.0$	(A > 1000 ha)

For serious accident:

▲$MK' = 10.0$	(A <100 ha)
▲$MK' = 7.5$	(A = 100 ~ 1000 ha)
▲$MK' = 5.0$	(A > 1000 ha)

In China, the standards of ordinary and serious accidents have been fixed by the government.

In Table 1, the sum of the weight of 16 indices is 0.90. Therefore, in general, the full mark of WAM of 16 indices is 90 and the full mark of WAM of an FMIS is 100. In Hubei Province, the standard for evaluating the performance in FMIS is:

$WAM \geq 90$	excellent
$WAM = 80 \sim 80.9$	good
$WAM = 70 \sim 70.9$	fair
$WAM = 60 \sim 60.9$	bare
$WAM < 60$	poor

APPLICATION OF THE PERFORMANCE EVALUATION METHOD IN A TYPICAL FMIS

The above mentioned method has been applied in some FMIS in Hubei Province in South China. As an example, the application of this method in Fushui Irrigation System (FIS) in Hubei Province is described below.

General Features of the Fushui Irrigation System

Fushui Irrigation District (FID) is situated in the central part of Hubei Province, North of the Changjiang (Yangtze) River. It was constructed in 1960. FIS is one of the FMIS in the hilly regions typical in South China, both in terms of its natural and social conditions and its performance and management level. The irrigated area of FID is 370 ha, of which about two-thirds lies in the hilly regions and one-third in the plain area. The soils of the area are mostly clay and loam. The main crops are rice and wheat. Rice is planted over 89 percent of FID and wheat is planted on 68 percent of the rice fields after harvest. The average annual evaporative capacity is 1,298.5 mm and rainfall is 1,033.1 mm, which is distributed in a highly irregular pattern both within and between years. Irrigation of rice is indispensable in both dry and wet years, and the irrigation periods are from

May to August. Irrigation is not necessary for wheat in any year. The annual yields of rice in FID was 6.1–7.3 t/ha during the 1980s.

The irrigation water of FIS is diverted mainly from the main canal of Xujiahe Irrigation System (XIS) which is a large-scale irrigation system of the Hubei Province. The main canal of FIS is one of the branch canals of XIS. There are one main canal and 51 branch canals of two ranks in FIS. The length of the main canal of FIS is 6.30 km and the capacity of this canal is 1.1 m^3/s. There are 407 ponds with a total capacity of 781 thousand m^3 which can provide 20 percent (in dry years) to 45 percent (in medium years) of the total irrigation water. It is thus clear that the ponds are a very important supplementary water source in FIS.

The management organization of this system was established in 1963. There is a management committee which is composed of the chairman, vice-chairman and three full-time members. All the members are village heads and farmers. Under the committee, there are seven management groups which are composed of 34 peasant management personnel and about 100 peasant irrigators. The responsibility of the organization and its members is to manage the irrigation structures, canals and ponds and to engage in water management and fields irrigation.

Evaluation of the Performance of the Fushui Irrigation System

Based on the material gathered, investigated and measured in FIS in 1988 (a median dry year), the performance of FIS in 1988 was evaluated by the method of WAM. The processes and results of calculating WAM of index system of FIS in 1988 are shown in Table 2.

Because the peasant management personnel had not been well-trained, the records, tables and charts of operation were not complete and the advanced technique had not been applied in FIS in 1988.

$$\blacktriangle MK_1 = \blacktriangle MK_2 = \blacktriangle MK_3 = 0$$

Because no accident occurred in 1988 due to the management personnel's negligence,

$$\blacktriangle MK' = 0$$

Thus, for FIS in 1988,

$$WAM = 75.0$$

This means that the grade of the performance of FIS in 1988 belongs to "fair." This grade is rather low for the historical conditions of FIS.

The causes of the unsatisfactory performance of FIS in 1988 can be found in Table 2. First, *MK* of No. 2 is too low. The reason is that the quantity of water supplied by the local water source ponds is much less than required. In the 1960s, the average annual quantity of water supplied by ponds in FIS was about 2,250 m^3/ha. But in the 1980s, it was only about 1,200 m^3/ha because the farmers abandoned the ponds and transformed them into rice fields to make up for the loss of farmland, which was occupied by local industry. Second, *MK* of No. 7 is low because there were six irrigation structures (water gates) which did not function normally. Third, *MK* of No. 9 and 10 are low because the total yield in 1988 lagged far behind the historical highest in 1984. Besides, an important additional mark —$\blacktriangle MK_1$ — is equal to zero because the peasant management personnel have not been trained, although the management organization was sound.

Table 2. Process and results of calculating WAM of index system of FIS in 1988.

No	Names, symbols and units of indices	Processes and results of calculating indices	Processes and results of calculating marks (*MK*=mark)	Values of weight (*WT*= weight)	*MK* * *WT*
1	Efficiency of irrigation water supply, *S*, (%)	$S=\frac{2.06 * 10^6}{2.456 * 10^6} * 100=84.0$	*MK*=84.0	0.03	2.52
2	Efficiency of utilizing local water resource within the irrigation district, *U*, (%)	$U=\frac{0.320}{0.616} * 100=51.9$	*MK*=51.9	0.06	3.11
3	Irrigation application efficiency, *E*	$E=0.84 * 0.83 * 0.87 * 1.00=0.607$	*MK*=100 * 0.607 * 1.4 =84.9	0.08	6.79
4	Percentage of actual irrigation water quota, *Pm*, (%)	$Pm=\frac{6100 * 0.607+300}{4200+300} * 100=89.0$	*MK*=50+0.5 * 89.0 =94.5	0.03	2.84
5	Percentage of actual irrigated area, *F*, (%)	$F=\frac{338}{365} * 100=92.6$	*MK*=2 * 92.6-100=85.2	0.08	6.82
6	Percentage of area provided with field irrigation and drainage systems, *D*, (%)	$D=\frac{320}{365} * 100=87.7$	*MK*=87.7	0.04	3.51
7	Percentage of facilities in good condition, *G*, (%)	$G=\frac{45}{51} * 100=95.1$	*MK*=2 * 88.2-100=76.4	0.08	6.11
8	Percentage of the highest yield per unit area, *Pya*, (%)	$Pya=\frac{7.18}{7.55} * 100=95.1$	*MK*=2 * 95.1-100=90.2	0.05	4.51
9	Percentage of the highest yield per unit quantity of irrigation water, *Pym*, (%)	$Pym=\frac{0.001177}{0.001358} * 100=86.7$	*MK*=2 * 86.7-100 =73.4	0.05	3.67
10	Percentage of the highest total yield, *Py*, (%)	$Py=\frac{2427}{2800} * 100=87.6$	*MK*=2 * 86.7-100 =73.4	0.10	7.34
11	Efficiency of collection of irrigation water charges, *P*1, (%)	$P1=\frac{9010}{1000} * 100=90.1$	*MK*=90.1	0.05	4.51
12	Percentage of the highest benefit, *PB*, (%)	$PB=\frac{177.5 * 10^3}{213.0 * 10^3} * 100=83.3$	*MK*=83.3	0.05	4.17
13	Percentage of financial self-sufficiency, *B*, (%)	$B=\frac{16.30 * 10^3}{12.14 * 10^3} * 100=131$	*MK*=100.0	0.05	5.00
14	Rate of change of groundwater table (*R*%)	$R=0$	*MK*=2.5(40-0)=100.0	0.05	5.00

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No	Names, symbols and units of indices	Processes and results of calculating indices	Processes and results of calculating marks (*MK*=mark)	Values of weight (*WT*= weight)	*MK* * *WT*
15	Percentage of the melioration of low-yield land, *Z*, (%)	$A_L = 0$	*MK*=90.0 0.08	7.20	
16	Percentage of afforestation of canals, *J*, (%)	$J = \frac{6.00}{6.30} * 100 = 95.2$	*MK*=95.2	0.02	1.90
	$WAM = \sum_{i=1}^{16} (MK_1 * WT_1)$			$\Sigma = 0.90$	$\Sigma = 75$

CONCLUSION

Measurement and evaluation of performance of FMIS in China are urgently required to improve their performance and to raise their management level. The performance of FMIS can be measured and evaluated by a method of quantitative analysis with the weighted average mark of an index system which consists of sixteen techno-economical indices of an FMIS. The present level of performance of FMIS, the major problems and their main causes can be clarified and the main measures for resolving the problems and improving the performance can be identified by applying the abovementioned method. The evaluation of the performance of a typical FMIS in South China has demonstrated the application of the method described. This type of evaluation can help to improve the performance, increase the crops yields and save on irrigation water in FMIS.

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