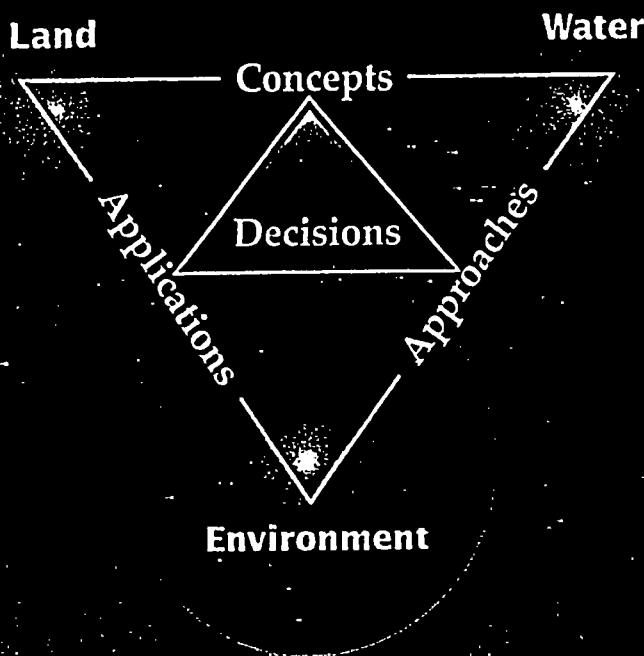


# Multiple Objective Decision Making for Land, Water, and Environmental Management

Proceedings of the First International Conference on  
Multiple Objective Decision Support Systems (MODSS)  
for Land, Water, and Environmental Management:  
Concepts, Approaches, and Applications



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## *Chapter 19*

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# **Effects of Optional Averaging Schemes on the Ranking of Alternatives by the Multiple Objective Component of a U.S. Department of Agriculture Decision Support System**

*BISHER IMAM, DIANA S. YAKOWITZ, AND LEONARD J. LANE*

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### **Abstract**

The effects of annual and long-term variations of climatological processes on the decision recommendations of a U.S. Department of Agriculture-Agricultural Research Service decision support system (DSS) and the effect that the point at which aggregation of information occurs in the system subprocesses are investigated. The objective of the system is to rank farm management alternatives in preference order consistent with their environmental and economical impacts. The decision-making process is divided into three subprocesses that include: (1) conversion of the simulation data values for each decision criteria into the unitless [0,1] domain through scoring, (2) computing best and worst composite scores, and (3) ranking the alternative management systems. In this study, four schemes were tested by changing the point at which data is aggregated using a stochastic

ensemble of model input. In all cases, the results were insensitive to the point at which the aggregation was performed and thus are supportive of the currently implemented choice to aggregate the simulation output prior to the first decision model subprocess.

## **Introduction**

Practical utilization of state-of-the-art water quality simulation models in identifying and aiding in the solution of nonpoint source pollution problems caused by agriculture was the motivation behind the development of a Water Quality Decision Support System (WQDSS), also known as MODeST (Multiple Objective Decision Support Tool) (Yakowitz et al., 1992; 1993c). The system, developed by the Agricultural Research Service (ARS) a branch of the U.S. Department of Agriculture, demonstrates the concept of coupling simulation models with multiobjective decision methods. The WQDSS integrates a field scale nonpoint source pollution and crop growth simulation models with a novel multiple criteria decision method in order to evaluate farm management systems and aid in the decision-making process. The WQDSS ranks a finite number of farm management systems in order of preference taking into account the effects of crop management, tillage operations, and nutrient and pesticide applications on water quality and economic attributes. These include sediment yield from the field, nutrient and pesticide loading, and net farm return. The current version of the WQDSS utilizes average annual values of the simulation data or historical record for each decision criteria to rank management alternatives. In this paper, we investigate the effects of stochastic decision criteria on the ranking of alternative systems using the WQDSS. The aim of the study is to evaluate the merit of using average annual values and suggest approaches that take into account the uncertainty in natural processes (e.g., precipitation, solar radiation, and temperature) in the decision-making process.

## **Description of the USDA-ARS WQDSS**

The following description of the WQDSS components is rather brief and readers are referred to Yakowitz et al. (1992 and 1993b,c) for details regarding the general structure of the system, and to Yakowitz et al. (1993a) for details regarding the theoretical background of the decision component. Other references are noted where appropriate.

### ***The Simulation Component***

The main part of the simulation component of the WQDSS is the Groundwater Loading Effects From Agricultural Management Systems (GLEAMS) (Leonard et al., 1987). GLEAMS simulates daily values of runoff, sediment and water movement in the root zone, and the pesticide distribution in each of these processes. This model was linked to the nutrient submodel from the Chemical, Runoff and Erosion from Agricultural Management Systems (CREAMS) model (Knisel, 1980) and the

crop growth component from the Erosion Impact and Productivity Calculator (EPIC) model (Williams et al., 1989). The modified GLEAMS accepts a daily precipitation input file and hydrology, sediment, pesticide, nutrient and crop growth parameter files. These parameter files must be designed to reflect management practices by using the user friendly input file builder in the system. The model's output consists of an annual summary file and a statistical summary file that includes minimum, maximum, and average annual values of several simulated processes.

### The Decision Component

Multiple criteria decision making associated with water quality problems involves evaluating a set of management alternatives with respect to a multitude of attributes that describe the natural system's responses. Generally, these attributes must be transformed from their original units into a common unit or unitless range such that an abstract total measure of performance of each alternative can be quantified. Following the suggestion of Lane et al. (1991), a set of 12 scoring functions (value functions) suggested by Wymore (1988) are used in the system to scale the decision criteria from their original units into unitless values in [0,1]. For each criterion or attribute, a function type is chosen and constructed using information from the decision maker or the default settings based on the input data.

Although the WQDSS decision component uses an additive value function (see Goichochea et al., 1982, for example) to aggregate the scores of the decision criteria, alternatives are not ranked based on a single set of weights. In fact, if partial information regarding the importance of each decision criterion is available, alternative ranking is attained by utilizing two simple yet powerful linear programs in order to obtain the best and worst possible composite scores considering all feasible sets of weights (Yakowitz et al., 1993a). Suppose that there are  $n$  alternatives which must be ranked in order of preference with respect to a vector of  $m$  decision criteria. If qualitative partial information regarding the relative order of each criterion is available, a criterion matrix,

$$\mathbf{X} = \left[ x_{ij} \right]_{\substack{i=1,2,\dots,m \\ j=1,2,\dots,n}}$$

may be defined by arranging the criteria in order importance. Hence,  $x_{ij}$  is the value of the  $i$ 'th most important decision criterion with respect to the  $j$ 'th alternative. Similarly, a scoring matrix,

$$\mathbf{V}(\mathbf{X}, \theta) = \left[ v_{ij} \right]_{\substack{i=1,2,\dots,m \\ j=1,2,\dots,n}}$$

may be defined as a function of  $\mathbf{X}$  as well as of the score function parameter vector  $\theta$ . The best and worst composite scores of an alternative consistent with the importance order are found according to Yakowitz et al. (1993a) by solving the following linear programs for the weights  $w_{i,t} = 1, 2, \dots, m$ .

$$BSC_j(WCS_j) = \max(\min) \sum_{i=1}^m w_i v_{ij} \tag{1}$$

$$st \sum_{i=1}^m w_i = 1$$

$$w_1 \geq w_2 \geq \dots \geq w_m \geq 0,$$

where in Equation 1:  $BCS_{jj}$  = best composite score of the  $j$ 'th alternative,  $WCS_{jj}$  = worst composite score of the  $j$ 'th alternative, and  $w$  = weight vector.

The first constraint of the above program normalizes the weights. The second constraint forces the solution to be consistent with the imposed importance order. Yakowitz et al. (1993a) showed that the extreme points of this program are defined by the following partial sums,  $s_{kj}$ ,  $k = 1, \dots, m$ :

$$s_{kj} = \frac{1}{k} \sum_{i=1}^k v_i \tag{2}$$

The analytic solution of Equation 1 is then given by:

$$BCS[V(X, \theta)] = [BCS_j] = \max_{k=1,2,\dots,m} [s_{kj}]_{j=1,2,\dots,n} \tag{3-a}$$

$$WCS[X, \theta] = [WCS_j] = \min_{k=1,2,\dots,m} [s_{kj}]_{j=1,2,\dots,n} \tag{3-b}$$

Once the best and worst possible composite scores of each alternative are identified, management alternatives can be ranked based on the average value of their best and worst composite scores (Yakowitz et al., 1993a). The average composite score (ABW) is,

$$ABW[V(X, \theta)] = [ABW_j] = \left[ \frac{BCS_j + WCS_j}{2} \right]_{j=1,2,\dots,n} \tag{4}$$

The solution of the multiple criteria decision-making problem is a vector of integers  $R$ , whose  $p$ 'th element  $r_p$  represents the index of the alternative holding the  $p$ 'th rank. Or,

$$R = \eta[ABW(V(X, \theta))] = [r_p]_{p \in \{1,2,\dots,n\}} \tag{5}$$

The function  $\eta$  is a descending ordering function that may be defined as follows:

$$\eta = r_p \in \{1, 2, \dots, n\}; \forall p = \{1, 2, \dots, n - 1\} ABW_{r_p} \geq ABW_{r_{p+1}} \tag{6}$$

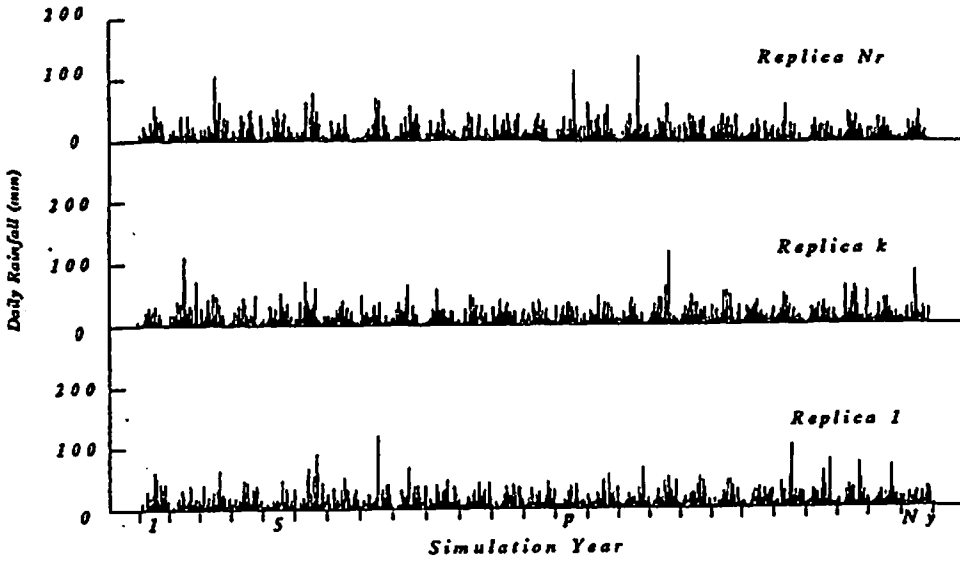


Figure 19.1 Example of a stochastic model input ensemble: daily precipitation. Generated using CLIGEN (Nicks and Lane, 1989) for Oakland, Iowa.

Since the method described above does not require specifying a weight vector, much of the subjectivity associated with multiple criteria decision making is eliminated.

### Stochastic Decision Criteria Values

We now consider random decision criteria for two purposes. One purpose is to account for the influence of the stochastic nature of climate processes on the ranking of farm management alternatives. The second is to assess the effect on the decision results of the points at which each of the three decision making subprocesses: (1) conversion from quantitative to qualitative values, (2) aggregation, and (3) ranking, is performed. In this study, conversion is defined as the application of a set of scoring functions to convert a decision criteria matrix  $X$  into a scoring matrix  $V(X, \theta)$ . Aggregation is the process of calculating the best and worst composite scores of a set of alternatives using Equations 2 through 4. Finally, ranking is defined as the ordering of a set of alternatives in preference based on their average best and worst composite scores utilizing Equations 5 and 6.

Consider a population of  $N_r$  samples of random sequences of model input (rainfall, temperature, radiation) such that each sequence of the ensemble consists of  $N_j$  annual observations of the simulation model input (a sample can be seen in Figure 19.1).

Introducing each input sequence to the simulation model yields a sequence of model output. Hence, the annual decision criteria matrix (model output) arranged in order of importance is written as

$$X = \left[ X_{kp} \right]_{\substack{k=1,2,\dots,N_r \\ p=1,2,\dots,N_j}} = \left[ X_{ijkp} \right]_{\substack{i=1,2,\dots,m \\ j=1,2,\dots,n \\ k=1,2,\dots,N_r \\ p=1,2,\dots,N_j}} \quad (7)$$

Table 19.1 Summary of the Four Ranking Schemes

Scheme	Description	Conversion	Aggregation	Ranking	Averaging prior to
a	Full ensemble	Annual	Annual	Annual	—
b	Average annual decision criteria for each replica	Replica	Replica	Replica	Conversion
c	Average annual scores of each replica	Annual	Replica	Replica	Aggregation
d	Average annual best and worst composite scores for each replica	Annual	Annual	Replica	Ranking

where  $[x_{ijkp}]$  is the simulation output value associated with the  $i$ 'th most important decision criterion with respect to the  $j$ 'th alternative occurring in the  $p$ 'th year of the  $k$ 'th replication sequence. To avoid lengthy notations we use the middle equality of Equation 7 to indicate the  $p$ 'th year of the  $k$ 'th replica of the random decision criteria matrix. Similarly a scoring matrix is written as

$$v(X, \theta) = [v(X_{kp}, \theta)] = [v_{ijkp}]_{\substack{i=1,2,\dots,n \\ j=1,2,\dots,n \\ k=1,2,\dots,N_r \\ p=1,2,\dots,N_y}} \tag{8}$$

The ranking vector obtained each year is then,

$$R_{kp} = r[ABW(v(X_{kp}, \theta))] \tag{9}$$

To study the effects of random decision criteria on the WQDSS recommendation, we calculate the frequency of occurrence of each alternative at a given rank obtained by four different schemes. Table 19.1 summarizes the four ranking schemes based on the point of application of each decision subprocess (conversion, aggregation, and ranking) and also indicates explicitly when averaging of the data takes place.

In scheme (a), all replicas are considered as a single sample of  $N_y \times N_r$  annual observations (simulations) of the random decision criteria. The alternatives are ranked annually and the frequency matrix FR is given by

$$FR = [FR_{t,j}]_{\substack{j=1,2,\dots,n \\ t=1,2,\dots,n}} = \left[ \frac{N[r_t = j]}{NT} \right]_{\substack{t=1,2,\dots,n \\ j=1,2,\dots,n}} \tag{10}$$

where  $N$  is the number of times at which alternative  $t$  occupies the rank  $j$  and  $NT$  is the total number of ranking vectors in the sample (in this case  $NT = N_y \times N_r$ ). Clearly, in the above scheme, conversion, aggregation, and ranking are all implemented annually.

In the second approach, b), each replica is a realization of the random sequence. Thus, there will be  $N_r$  samples whose expected value (sample mean) of the decision criteria matrix is:

$$E[\mathbf{X}]_k = \frac{\sum_{p=1}^{N_y} \mathbf{X}_{kp}}{N_y}, k = 1, 2, \dots, N_r. \quad (11)$$

In this case, the scoring matrix and the average composite score vectors are functions of the sample mean of the decision criteria matrix for each replica of the ensemble.

$$\mathbf{V}(E[\mathbf{X}]_k, \theta) = [\mathbf{v}_{ij}]_k, k = 1, 2, \dots, N_r. \quad (12)$$

$$\mathbf{ABW}_k = \mathbf{ABW}(\mathbf{V}(E[\mathbf{X}]_k, \theta)), k = 1, 2, \dots, N_r. \quad (13)$$

Similarly, the ranking vector becomes a function of the scores of the replica's average annual criteria matrix.

$$\mathbf{R}_k = \eta[\mathbf{ABW}(\mathbf{V}(E[\mathbf{X}]_k, \theta))], k = 1, 2, \dots, N_r. \quad (14)$$

Applying Equation 14 to all replicas within the ensemble yields a sample of  $N_r$  ranking vectors. The ranking frequency matrix  $\mathbf{FR}$  is given by Equation 10 with  $NT = N_r$  (the number of replicas in the ensemble). Unlike the first scheme, this scheme averages the decision criteria matrix with respect to each replica. Hence, conversion, aggregation, and ranking are all performed on the replica level. In approach (c), the decision criteria are scored annually to produce a scoring matrix for each year  $p$  within a replica  $k$ . The average annual scoring matrix for each replica is then:

$$E[\mathbf{V}(\mathbf{X}_{kp}, \theta)]_k = \frac{\sum_{p=1}^{N_y} \mathbf{V}(\mathbf{X}_{kp}, \theta)}{N_y}, k = 1, 2, \dots, N_r. \quad (15)$$

The average composite score for each replica is determined by solving (3-a and b) using the replica's average annual scoring matrix. The alternatives are ranked according to:

$$\mathbf{R}_k = \eta[\mathbf{ABW}(E[\mathbf{V}(\mathbf{X}_{kp}, \theta)]_k)], k = 1, 2, \dots, N_r. \quad (16)$$

Again, a sample of  $N_r$  ranking vectors result by applying Equations 15 and 16 to each ensemble replica. Hence, ranking frequency can be obtained using Equation 10 with  $NT = N_r$ . This scheme differs from the two previous schemes in that conversion is implemented annually, while aggregation and ranking are both



performed on the replica scale. The interface between the two temporal levels is provided by the sample expectation operation described in Equation 15.

In the last approach, (d), the decision criteria matrices are scored and the best and the worst composite score vectors are determined annually and the replica sample mean calculated by:

$$E\left[\text{BCS}\left(\mathbf{v}\left(\mathbf{X}_{kp}, \theta\right)\right)\right]_k = \frac{\sum_{p=1}^{N_y} \text{BCS}\left(\mathbf{v}\left(\mathbf{X}_{kp}, \theta\right)\right)}{N_y}, k = 1, 2, \dots, N_r. \quad (17-a)$$

$$E\left[\text{WCS}\left(\mathbf{v}\left(\mathbf{X}_{kp}, \theta\right)\right)\right]_k = \frac{\sum_{p=1}^{N_y} \text{WCS}\left(\mathbf{v}\left(\mathbf{X}_{kp}, \theta\right)\right)}{N_y}, k = 1, 2, \dots, N_r. \quad (17-b)$$

The alternatives are then ranked based on the average best/worst composite score:

$$E\left[\text{ABW}\left(\mathbf{v}\left(\mathbf{X}_{kp}, \theta\right)\right)\right]_k = \frac{E\left[\text{BCS}\left(\mathbf{v}\left(\mathbf{X}_{kp}, \theta\right)\right)\right]_k + E\left[\text{WCS}\left(\mathbf{v}\left(\mathbf{X}_{kp}, \theta\right)\right)\right]_k}{2}, \quad (18)$$

$$k = 1, 2, \dots, N_r,$$

Thus, the ranking vector is,

$$\mathbf{R}_k = \eta\left[E\left[\text{ABW}\left(\mathbf{v}\left(\mathbf{X}_{kp}, \theta\right)\right)\right]_k\right], k = 1, 2, \dots, N_r. \quad (19)$$

Applying Equation 19 to each replica within the ensemble yields a sample of  $N_r$  ranking vectors. The ranking frequency is then determined using Equation 10 with  $NT = N_r$ . From Equations 18 and 19, it is clear that in this case, conversion and aggregation are both performed on the annual scale, while ranking is performed on the replica scale. Similar to the latter two schemes, this transition between the two temporal scales is provided by the averaging operation described in Equation 17.

## Case Study: Treynor, Iowa

### Background

The above discussed schemes were applied to a 32-ha watershed monitored by the USDA-ARS Deep Loess Research Station near Treynor, Iowa. Historical records of 24 years including rainfall, runoff, percolation, sediment yield, nutrient and pesticide applications and crop yield are available. The current tillage practice on the watershed is deep disking with continuous corn [DD\_CC]. To illustrate the

above approach, a set of four alternative management systems are proposed for the field. These systems are (1) deep disking and corn — soybean rotation [DD\_CB], (2) chisel plow and corn — soybean rotation [CP\_CB], (3) ridge till and corn — soybean rotation [RT\_CB], and (4) no till and corn — soybean rotation [NT\_CB]. All five practices (including the conventional) must be evaluated with respect to a vector of sixteen decision criteria and two different importance orders. The first importance order considers five nutrient loading decision criteria as the most important. The first seven criteria in order are (1) nitrogen concentration in runoff, (2) nitrogen concentration in sediment, (3) nitrogen concentration in percolation, (4) phosphorus concentration in runoff, (5) phosphorous concentration in sediment, (6) sediment yield, and (7) net farm return. Among eight different pesticides applied in one or more of the five management practices, only four were predicted by the simulation model to show traces significant enough to be considered in the decision-making process. These pesticides were Alachlor,\* Atrazine,\* Bromoxynil,\* and 2,4-D.\* The importance order of the decision criteria associated with these pesticides is (8) Alachlor in runoff, (9) Alachlor in sediment, (10) Atrazine in runoff, (11) Atrazine in sediment, (12) Bromoxynil in runoff, (13) Bromoxynil in sediment, (14) 2,4-D in runoff, (15) Atrazine in percolation, and (16) 2,4-D in percolation. The second importance order considered net farm return to be the most important decision criterion and the order of all remaining criteria were shifted accordingly. The two importance orders are summarized in Table 19.2.

To parameterize the sixteen scoring functions historical climatological record was used in the simulation of the conventional management system. The average annual value of each decision criterion was used to determine the baseline parameters for each corresponding scoring function. Farm returns were calculated using a simplified cost benefit equation in which benefits were assumed to result from the sale of crop at the average prices estimated for the period between 1988 and 1990 (USDA, Agricultural Statistics, 1991). Average values of production cost were estimated using the Cost and Return Estimator (CARE) model (Midwest Agricultural Research Associates, 1988). Input to the model consisted of farm management operations including tillage, nutrient and pesticide applications, and labor costs (Heilman et al., 1993). The CARE model input was obtained from the Iowa Soil Conservation Service. Table 19.3 lists the sale prices and the costs associated with a typical crop year given the tillage practice as estimated by CARE.

### ***Historical Weather Record***

The above management alternatives were evaluated using the available historical record prior to performing the stochastic experiment. To do so, the 24-year historical climatological record was used in the simulation of the four alternative and the conventional management systems. The five resulting alternative output sequences were considered as a single replica and the four ranking schemes

\* The USDA neither guarantees nor warrants the standard of the products mentioned above, and the use of the names by the USDA implies no approval of the product to the exclusion of others that may also be suitable.

**Table 19.2 Two Importance Orders of the Decision Criteria Considered in the Experiment**

		<i>Importance order</i>	
		<i>#1</i>	<i>#2</i>
1	N in runoff		Net returns
2	N in sediment		N in runoff
3	N in percolation		N in sediment
4	P in runoff		N in percolation
5	P in sediment		P in runoff
6	Sediment yield		P in sediment
7	Net returns		Sediment yield
8	Lasso in runoff		Lasso in runoff
9	Lasso in sediment		Lasso in sediment
10	Aatrex in runoff		Aatrex in runoff
11	Aatrex in sediment		Aatrex in sediment
12	Buctril in runoff		Buctril in runoff
13	Buctril in sediment		Buctril in sediment
14	Dacamine in runoff		Dacamine in runoff
15	Aatrex in percolation		Aatrex in percolation
16	Dacamine in percolation		Dacamine in percolation

**Table 19.3 Estimated Production Costs and Sales Prices for Treynor, Iowa**

<i>Crop</i>	<i>Sales price \$/mg</i>	<i>Production costs (\$/HA)</i>			
		<i>Deep disk</i>	<i>Chisel plow</i>	<i>Ridge till</i>	<i>No till</i>
Corn	90.75	180.00	178.00	164.00	146.00
Soybean	228.43	375.00	350.00	289.00	281.00

described in Table 19.1 were used to rank the alternatives in order of preference. Since only one replica is available ( $N_r = 1$ ,  $N_y = 24$ ), only scheme (a) yielded frequency data given in Figure 19.2. For this case schemes (b), (c), and (d) yielded a single observation of the ranking vector for each scheme and each importance order results are listed in Table 19.4. Notice that in Table 19.4, the conventional practice [DD\_CC] has an average best and worst composite score (ABW) of 0.5 for both importance orders using scheme (b). This occurs since the average annual value of each decision criterion is used to define the baseline parameter for each corresponding scoring function. On the other hand, when ranking schemes (c) and (d) are used the conventional practice's composite score varied from 0.5.

When using ranking scheme (a), it is reasonable to recommend as best that alternative that has the maximum frequency of ranking first. From Figure 19.2, alternative [RT\_CB] is recommended when nutrient related decision criteria are most important (importance order I) while the alternative [NT\_CB] is recommended when the economical criterion supersedes the environmental criteria (importance order II). However, from Table 19.4 we see that the numerical values of the

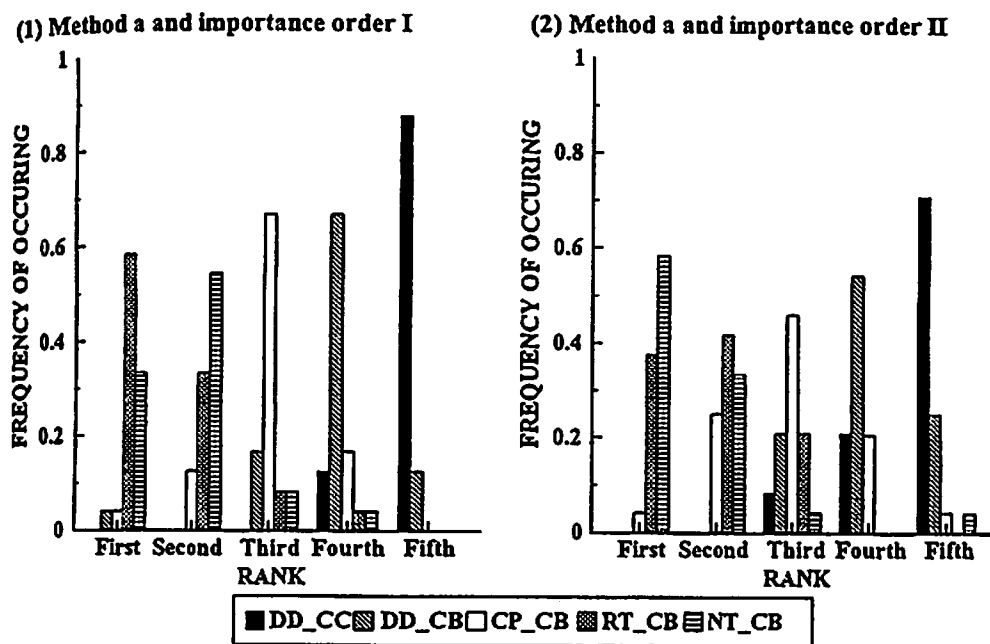


Figure 19.2 Ranking frequency for five management alternatives simulated for 25 years of historical climatologic record. Treynor, Iowa.  $N_y = 24$  years,  $N_r = 1$  replica.

average best/worst composite scores of the first two alternatives [RT\_CB] and [NT\_CB] were quite close for both importance orders when schemes (b), (c), and (d) were applied indicating the competitive nature of these two management systems.

### Stochastically Generated Weather

As mentioned, GLEAMS accepts daily rainfall data, monthly minimum and maximum temperature, and monthly mean radiation. In this part of the experiment we use the weather generator CLIGEN (Nicks and Lane, 1989) to generate 125-year replications of data for the station nearest to Treynor (Oakland, Iowa). Input sequences (125-year) were deemed more desirable than a single 2,500-year sequence for the following reasons. First, independent sequences are needed to understand the behavior of each management alternative under varying condition. Second, the modified GLEAMS simulation model is limited to a 40-year simulation. For each sequence the following steps were applied. First, a randomly generated seed was introduced to CLIGEN with the necessary information. Second, generated daily rainfall data was then read and written to a GLEAMS precipitation file. Temperature and radiation data were averaged for each month during every year and then used with the GLEAMS hydrology parameter files corresponding to the five management systems. Third, the simulation was performed for each alternative system using the stochastic precipitation and hydrology files along with the erosion, nutrient, pesticide, and crop growth files. The annual crop yield was used to calculate the annual farm net return based on the information provided

**Table 19.4 Alternative Ranking Based on Three Averaging Schemes of Decision Criteria Simulated using 24 years of Historical Record in Treynor, Iowa**

Scheme # Rank	<i>Importance order I</i>						<i>Importance order II</i>					
	<i>b)</i>		<i>c)</i>		<i>d)</i>		<i>b)</i>		<i>c)</i>		<i>d)</i>	
	<i>(1)</i> Alt	<i>(2)</i> ABW	<i>(3)</i> Alt	<i>(4)</i> ABW	<i>(5)</i> Alt	<i>(6)</i> ABW	<i>(7)</i> Alt	<i>(8)</i> ABW	<i>(9)</i> Alt	<i>(10)</i> ABW	<i>(11)</i> Alt	<i>(12)</i> ABW
1	RT_CB	0.826	RT_CB	0.798	RT_CB	0.785	NT_CB	0.789	NT_CB	0.768	NT_CB	0.742
2	CP_CB	0.817	NT_CB	0.793	NT_CB	0.782	RT_CBB	0.732	RT_CB	0.732	RT_CB	0.718
3	NT_CB	0.716	CP_CB	0.712	CP_CB	0.700	CP_CB	0.687	CP_CB	0.689	CP_CB	0.663
4	DD_CB	0.621	DD_CB	0.653	DD_CB	0.644	DD_CB	0.519	DD_CB	0.615	DD_CB	0.591
5	DD_CC	0.500	DD_CC	0.542	DD_CC	0.527	DD_CC	0.500	DD_CC	0.546	DD_CC	0.538

Ny = 24 year, Nr = 1 replica.

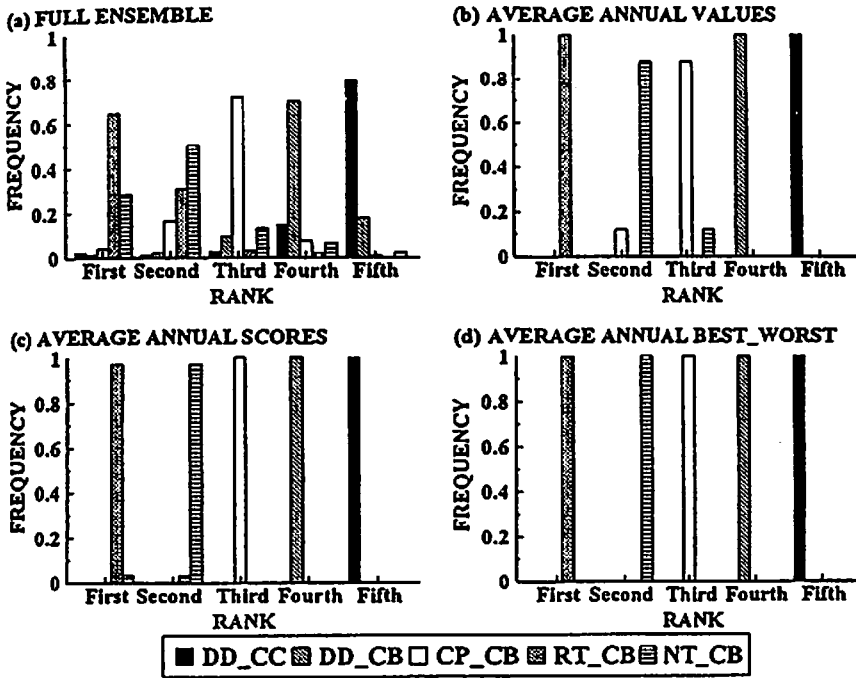


Figure 19.3 Frequency of alternative ranking for four different ranking schemes when nutrient impact on water quality is more important than farm return.

in Table 19.3. Once all simulation runs were completed, the ranking experiments described by Equations 9 through 19 were performed.

Equation 10 was used to determine the frequency of occurrence of an alternative at a given rank while Equations 11, 15, and 18 were used to estimate the mean values for the last three experiments with  $N_y = 25$  years per replica and  $N_r = 100$  replicas in the ensemble.

Figure 19.3 illustrates the results of the frequency analysis when the first importance order is imposed. As indicated, alternative [RT\_CB] dominates the first position throughout the experiment. However, there were instances in which other alternatives were ranked first, especially when the whole ensemble was treated as a single sample (Figure 19.3-a). The maximum frequency of occurrence with respect to this case would yield the following order: [RT\_CB], [NT\_CB], [CP\_CB], [DD\_CB], and finally [DD\_CC]. The remaining schemes are consistent with this order. The ranking indicated by Figure 19.3-d provides the most evident ordering since only a single alternative occupies a given rank.

Similar behavior was also observed with respect to the second imposed importance order (Figure 19.4). (Recall that, in this case, net returns has the highest priority.) All schemes produced the following ranking: [NT\_CB], [RT\_CB], [CP\_CB], [DD\_CB], and [DD\_CC]. However, there were instances in which alternative [RT\_CB] ranked first for schemes (a) (b) and (c) indicating the competitive nature of the first two alternatives. Again, scheme (d) provided the most decisive ranking.

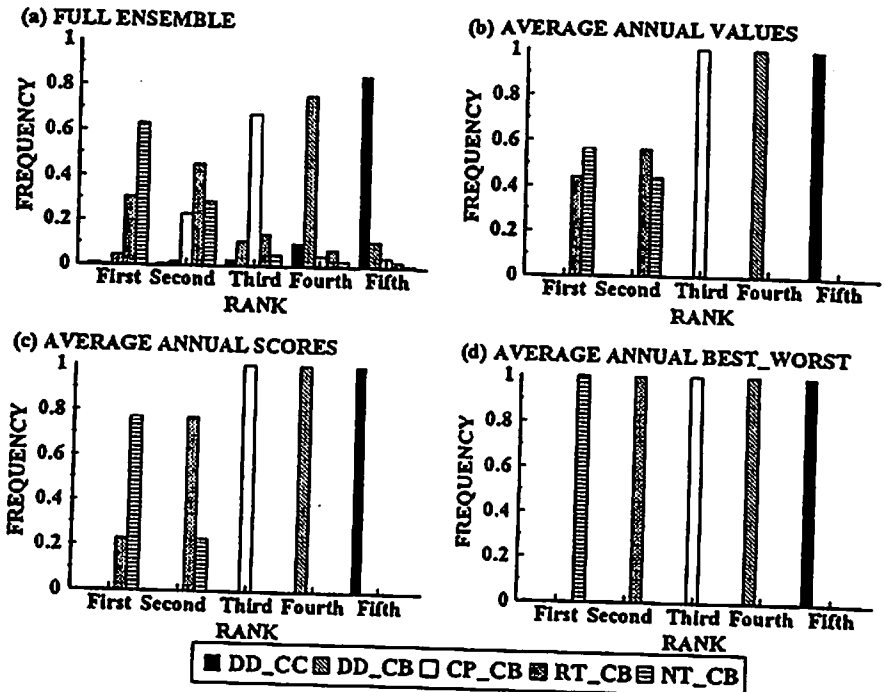


Figure 19.4 Frequency of alternative ranking for four different ranking schemes when farm return is considered the most important decision criterion.

## Summary and Conclusion

Four different schemes for ranking a discrete set of management systems were used in conjunction with the USDA-ARS WQDSS. The four schemes differ among each others with respect to the temporal level at which the quantitative decision criteria matrix is converted into a qualitative scoring matrix and aggregated using the best and worst possible composite scores for each alternative. Two temporal levels were considered, the annual level and the replica level.

The four schemes were tested for two different importance orders reflecting two possible resource management strategies to be used to evaluate five different farm management systems. Then, 100 sequences of stochastically generated climatological data were used to provide 100 replicas of simulation output for the same five management systems. In this case, the final ranking vector corresponding to each ranking scheme was determined by observing which alternative had the maximum frequency of occurrence at a given rank.

With respect to the first importance order, all schemes produced the same ranking of the alternatives for both the historical record and the stochastically generated record. Similarly, the ranking produced by applying the above four schemes to the second importance order produced identical results for both the historical and the stochastic experiments. The consistency of the schemes suggests that the decision model is insensitive to the point at which the expectation (averaging) operation is performed.

Similarities between the results of each scheme when applied to the historical record and when applied to the stochastic record indicate that the random generator, CLIGEN, successfully reproduced the general behavior of the climatological record for the area under study. Furthermore, similarities between the ranking vectors obtained from all ranking schemes with respect to each importance order suggests that the currently used approach in the WQDSS may be adequate (ranking is currently based on the average annual values of the decision criteria, the least computationally cumbersome approach since averaging is done prior to conversion). Nevertheless, the information generated by each of the four schemes can be of value to a decision maker. For example, scheme (a) when used for a reasonably long historical record, allows the decision maker to evaluate the impact of the annual variation of the climatological processes on the decision-making process. These variations may include extreme events for which management alternatives respond differently. Schemes (b) and (c), on the other hand, exert a smoothing effect on the average best/worst composite scores of competing alternatives, hence, providing a more discerning evaluation of competitive alternatives than scheme (a). Finally, scheme (d) appears to produce the most conclusive ranking.

The above discussion exemplifies the benefits of considering more than one ranking strategy when the decision-making problem includes closely competing alternatives. Decision makers can gain different perspectives by using all of the above schemes.

If the historical record is reasonably long, as in this example, applying the above four schemes to the historical record alone may exhibit sufficient information to assess the effects of the annual variation in the climatological processes on the decision recommendations, hence avoiding the burden of a stochastic experiment.

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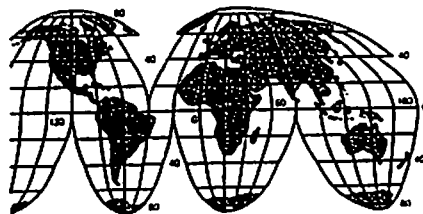
S.A. El-Swaify

Department of Agronomy and Soil Science  
College of Tropical Agriculture and Human Resources  
University of Hawaii  
Honolulu

and

D.S. Yakowitz

U.S. Department of Agriculture  
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