벼 調製 및 貯藏 시스템의 最適化를 위한 非線型 골 프로그래밍(Ⅱ)+

Nonlinear Goal Programming for Optimizing Rice Conditioning and Storage Systems: Part Ⅱ … Application+

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摘 要

MODM (Multiple Objective Decision Making) 問題로서의 벼 乾燥 및 貯藏施設의 設計問題에 NGP(Nonlinear Goal Programming)를 利用하여 어떻게 適正化할 수 있는가를 例題를 통하여 提示한 후, 1,762㎥의 收穫量에 대한 6가지의 벼 乾燥 및 貯藏施設에 대한 각각의 適正시스템을 提示하였다.

I. Introduction

Since the model which can be applied to small scale problems, sometimes does not work well for the large scale real world problems, it is a necessary step to test the model after mathematical modeling to determine whether it works satisfactorily for real world problems. Also, model application examples are needed to illustrate the methods and procedures of model application.

Loewer et al. (1976) studied the influences of number of storage bins, daily harvest rate and degree of mechanization for the three drying techniques; layer, batch-in-bin and portable.

Bridges et al. (1979) used the design computer simulation to determine the influence of harvest rate and drying time on corn drying and storage facility selection. From their study, they showed that the break-point of on-farm storage after drying ranged from 116.3 to 133.9 m^3 per day.

Chang et al. (1979a) developed a mathematical model for dryer selection of corn drying. And they suggested that batch-in-bin drying was the least cost system for volumes ranging from 704.8 to 2,466.8 m^3 per year.

The previous works described above have the characteristic that the systems were designed or selected by restricting the analysis having a single objective which is a minimum cost. But, the real world problems almost invariablly are characterized by multiple, conflicting objectives. Consequently, if we attempt to describe such multiple objective problems by single objective models, then we should not be surprised when the answers derived from such restricted models fail to yield satisfactory results for special situations.

The objectives of this study were to demonstrate the application of the MODM (Multiple Objective Decision Making) method for a specific example problem comprising of six different rough rice drying and storage systems, and to develop optimum systems

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of rough rice drying and storage of 1,762 m^3 harvest volume by NGP (Nonlinear Goal Programming).

II. Application of NGP

A. Procedures of System Design

The procedures of system design by nonlinear goal programming are:

1) Set up a problem for system design.

2) Analyze a problem and develop mathematical models describing a system or systems which are needed to formulate the problem for NGP.

3) Formulate the problem for NGP problem.

4) Optimize the problem using NEWINGP program (Hwang and Masud, 1979).

5) Redesign the systems, if the results of optimization are not satisfactory, until they reach the satisfactory level.

6) Select the best system among the optimum systems.

B. Example Problem

An example problem comprizes of six different rough rice drying and storage systems which are: a) natural air drying; b) natural air drying with supplemental heat; c) layer drying; d) batch-in-bin drying; e) batch-in-bin drying with stirrer; and f) combination drying, batch-in-bin drying with stirrer followed by natural air drying. The general characteristics of an example problem are:

1) System capacity required is 1,762 m^3 per year. According to 1979 Taxas Field Crop Statistics, the average yield of rough rice per harvested hectare is 8.9 m^3 in 1979, and the average size of farms in the United States is 182.1 ha. Hence, the average rice production level per farm can be approximated to 1,762 m^3 per year.

2) The grain is rough rice which is dried from 22 percent to 12.5 percent of moisture content, wet basis. The moisture content of safe storage is 12.5 percent and the average harvesting moisture content is 22 percent, wet basis (Sorenson and Crane, 1960)

3) The harvesting period of rough rice starts on August 20 and ends on September 10. Generally, the harvesting starts on the third week of August and ends on the first week of September in the Texas rice growing area. Therefore, the harvesting period is assumed to be 20 days in the example.

4) The average weather conditions of the harvesting period are: temperature is 26.7°C and relative humidity is 81 percent. This data was obtained from the official weather data of Beaumont, Texas, which is the average of 15 years data (1962 through 1976) provided from the National Weather Bureau Center, Ashville, North Carolina.

5) Aeration is assumed to be continued to December 31 (around 3.5 months).

6) Airflow rate of aeration for storage is 0.08 m^3 of air/min-m^3 (Houston, 1972; Sorenson and Crane, 1960).

7) Airflow rate of dryeration is 0.4 m^3/min-m^3 (Brooker et al., 1974).

8) Tempering time and cooling time for dryeration are assumed to be 5 and 12 hours, respectively (Houston, 1972; Luh, 1980; Steffe, 1979).

9) Fan and motor efficiency is assumed to be 60 percent.

10) The efficiency of gas combustion is assumed to be 90 percent (Young and Dickens, 1975).

11) Possible systems constraints are:

Fan motor size $\leq$ 14.9 kW
Heater size $\leq$ 1172.3 kW
Number of bin $\geq$ 1
Bin diameter (4.6 - 14.6 m)
Bin eave height (3.4 - 7.9 m)
Bin bed depth (Table 1)

12) Variable names are:

X_1 = diameter of drying bin
X_2 = eave height of drying bin
X_3 = grain bed depth of drying bin
X_4 = diameter of dryeration bin
X_5 = eave height of dryeration bin
X_6 = grain bed depth of dryeration bin

X_7 = diameter of storage bin

X_8 = eave height of storage bin

X_9 = grain bed depth of storage bin

13) Economic information (USDA, 1980a and 1980b; USDOE 1980):

Natural gas price = 1.21 \$/mil. kJ

Electricity = 0.056 \$/kW-h

Labor cost = 3.6 \$/h

Price of rough rice = 134.2 $\$/m^3$ (No. 2 grade)

144.8 $\$/m^3$ (sample grade)

The specific system parameters shown in Table 1 are estimated based on general characteristics stated and the following assumptions:

1) The maximum drying air temperature is assumed to be 48.9°C for batch-in-bin and in-bin drying (Arora et al., 1973).

2) Drying airflow rates for natural air drying systems are recommended by Sorenson and Crane (1960). For other drying systems, they are determined by the model.

3) Aeration airflow rate is 0.08 $m^3/min\text{-}m^3$(Sorenson and Crane, 1960: Houston, 1972).

4) The maximum drying bed depths of natural air drying systems were assumed, according to the recommendations by Sorenson and Crane (1960), and Chang et al. (1979b). For batch-in-bin drying with and without stirring device, they were assumed as Midwest Plan Service (1977) recommended.

5) The efficiencies of the different drying systems were assumed, according to the recommendations by Chang et al. (1979a), and Bridges (1974).

6) Dryer operation hours per day were assumed as those in Table 1. Drying time for natural air drying was assumed, based on the recommendations by Sorenson and Crane (1960), and Chang et al. (1979a). For layer drying, drying days are assumed to be 23 days, because Calderwood (1966) showed that the high moisture rice (22 percent, wet basis) can be stored safely for 3 days with aeration.

7) Storage times were determined for the grain stored in the storage bin. The storage time for the grain stored in dryeration bin and drying bins should be considered carefully and differently.

8) The difference of humidity ratio and enthalpy are the differences between the ambient air conditions and the heated air conditiions.

9) The weight ratio of grain moisture is different with drying systems. Since the batch-in-bin drying systems included the dryeration process, the actual moisture removal by drying process is two points less than that of in-bin systems.

10) In combination drying, rice is dried from 22 percent to 18 percent by batch-in-bin drying with stirrer, and from 18 to 12.5 percent, wet basis, by natural air drying.

C. Formulation of NGP Problem for Example Problem

Using model systems and mathematical models with general characteristics and specific system parameters given in Table 1, the MODM problem can be formulated for the example problem. In this problem, since grain damage is not dependent on the system size, two objectives which are cost minimization and energy input minimization are considered.

The following is the problem formulation for a rough rice drying and storage system by batch-in-bin drying with stirrer:

$$\text{Min. } f_1(\underline{X}) = Z_1 + P_f Z_2 + P_e Z_3 + P_m Z_4 + 0.01\, P_g V Z_5 \qquad (1)$$

$$\text{Min. } f_2(\underline{X}) = 2.78\times10^{-4} Z_2 + Z_3 + 0.19\, Z_4 \qquad (2)$$

subject to

$$\left.\begin{aligned} &g_1(\underline{X}) = K \geqslant 1\\ &g_2(\underline{X}) = M \geqslant 1\\ &g_3(\underline{X}) = N \geqslant 1\\ &g_4(\underline{X}) = HP_d \leqslant 14.9\\ &g_5(\underline{X}) = HEAT \leqslant 1172.3\\ &g_6(\underline{X}) = X_5 - X_6 - X_6 \geqslant 0\\ &g_7(\underline{X}) = X_8 - X_9 \geqslant 0\\ &4.6 \leqslant X_1 \leqslant 14.6\\ &3.4 \leqslant X_2 \leqslant 7.9\\ &1.8 \leqslant X_3 \leqslant 2.7\\ &4.6 \leqslant X_4 \leqslant 14.6\\ &3.4 \leqslant X_5 \leqslant 7.9\\ &0.6 \leqslant X_6 \leqslant 7.9 \end{aligned}\right\} \qquad (3)$$

Table 1. Specific system parameters for example problem

System parameter \ Systems*	NA	NASH	LAY	BIB	BIBS
1. Drying air temperatature, ℃	26.7	30.6	37.8	48.9	48.9
2. Drying airflow rate, m³/min-m³	2.0	0.8	········ by model ········		
3. Aeration airflow rate, m³/min-m³	0.08	0.08	0.08	0.08	0.08
4. Drying bed depth, m	1.8−2.4	1.8−2.4	1.8−7.3	0.6−1.2	1.8−2.7
5. Drying efficiency, %	70	70	70	40	60
6. Dryer operation, hours per day	24	24	24	17	17
7. Drying time, hours per year	1200	707	552	340	340
8. Aeration time, hours per year	1992	2485	2640	2688	2688
9. Specific volume of air, m³/kg	0.87	0.87	0.87	0.78	0.87
10. Humidity ratio difference, kg water per kg dry air	0.	0.0023	0.0047	0.0084	0.0084
11. Enthalpy difference, kJ/kg	0.	3.26	12.10	24.19	24.19
12. Moisture weight ratio, WR**	0.1086	0.1086	0.1086	0.0877	0.0877

*NA =Natural air drying
NASH=Natural air drying with supplemental heat
LAY =Layer drying
BIB =Batch-in-bin drying
BIBS =Batch-in-bin drying with stirrer
**WR =M_o-M_f / (100−M_f), M_o, M_f =initial and final moisture content, %

$$4.6 \leqslant X_7 \leqslant 14.6$$
$$3.4 \leqslant X_8 \leqslant 7.9$$
$$3.0 \leqslant X_9 \leqslant 7.9$$

where

$f_1(\underline{X})$ = cost function, $/year
$f_2(\underline{X})$ = energy function, kW-h/year
$g_i(\underline{X})$ = systems contraints, i = 1, ... 7
Z_1 = sum of fixed costs, $/year
Z_2 = heat requirement of heater, kJ/year
Z_3 = sum of electric requirement of system, kW-h/year
Z_4 = labor requirement, man-h/year
Z_5 = sum of the grain damage percent, %
K = number of drying bin, integer
M = number of dryeration bin, integer
N = number of storage bin, integer
HP_d = fan size for drying, kW
HEAT = heater size, kW
P = prices
V = grain volume

The above problem can be reformulated for a NGP problem with multiple objectives. In this example, the first priority is given to minimization of cost, and the second priority is given to minimization of energy inputs. The following shows the NGP problem for the Equations (1), (2) and (3). As it is explained in the section of NGP (Part I Modeling, Vol. 8, No. 2, KSAM, 1983), all the objective functions and constraint functions are converted to the equaling constraints by the under-achievement (d_i^-)

and the over-achievement (d_i^+), and they became the constraints functions. Then, the deviational variables which are to be minimized, are selected by the procedure described in the section of NGP.

$$\text{Min} \quad (d_1^- + d_2^- + d_3^- + d_4^+ + d_5^+ + d_6^- + d_7^-), d_8^+, d_9^+$$

$$f_1(\underline{X}) = K + d_1^- - d_1^+ = 1$$

$$f_2(\underline{X}) = M + d_2^- - d_2^+ = 1$$

$$f_3(\underline{X}) = N + d_3^- - d_3^+ = 1$$

$$f_4(\underline{X}) = HP_d + d_4^- - d_4^+ = 14.9$$

$$f_5(\underline{X}) = HEAT + d_5^- - d_5^+ = 1172.3$$

$$f_6(\underline{X}) = X_5 - X_6 + d_6^- - d_6^+ = 0$$

$$f_7(\underline{X}) = X_8 - X_9 + d_7^- + d_7^+ = 0$$

$$f_8(\underline{X}) = Z_1 + P_f Z_2 + P_e Z_3 + P_m Z_4 + 0.01 P_g V Z_5 + d_8^- - d_8^+ = 0$$

$$f_9(\underline{X}) = 2.78 \times 10^{-4} Z_2 + Z_3 + 0.19 Z_4 + d_9^- - d_9^+ = 0$$

$$4.6 \leqslant X_1 \leqslant 14.6$$

$$3.4 \leqslant X_2 \leqslant 7.9$$

$$1.8 \leqslant X_3 \leqslant 2.7$$

$$4.6 \leqslant X_4 \leqslant 14.6$$

$$3.4 \leqslant X_5 \leqslant 7.9$$

$$0.6 \leqslant X_6 \leqslant 7.9$$

$$4.6 \leqslant X_7 \leqslant 14.6$$

$$3.4 \leqslant X_8 \leqslant 7.9$$

$$3.0 \leqslant X_9 \leqslant 7.9$$

Similarly, the problems for other drying and storage systems can be transformed into NGP problems with multiple objectives. Then, these problems are solved by NEWINGP program to design the optimum systems.

III. Results and Discussion

The following is the computation results for the batch-in-bin drying with stirrer:

1) $X_1 = 10.4$ m, $X_2 = 7.9$ m, $X_3 = 1.8$ m, $K = 0.6$
2) $X_4 = 4.6$ m, $x_5 = 7.9$ m, $X_6 = 5.4$ m, $M = 1.0$
3) $X_7 = 14.6$ m, $X_8 = 7.9$ m, $X_9 = 7.9$ m, $N = 1.2$
4) Cost = 11,616.6 \$/year
5) Energy Input = 83,211.6 kW-h/year
6) Grain Damage = 2.75 %/year

At this stage, the designer should examine the results carafully whether they are satisfactory or not. The following portions of the results are not satisfactory.

1) The diameter of drying bin (X_1) should be a multiple of 0.91 m. Also the number of drying bins (K) should be more than one and be integer.

2) Being compared with the bed depth, the eave height of dryeration bin (X_5) is too high.

3) The number of storage bins (N) should be integer (either one or two). The number, 1.2, shows that the number better be two. Based on this analysis of results, further computations are tried with the real world data. The following results are obtained as a final solution of NGP problem, which are optimal for the minimization of cost and energy input:

(1) $X_1 = 5.5$ m, $X_2 = 3.4$ m, $X_3 = 1.9$ m, $K = 2$
(2) $X_4 = 4.6$ m, $X_5 = 5.5$ m $X_6 = 5.4$ m, $M = 1$
(3) $X_7 = 13.7$ m, $X_8 = 6.6$ m, $X_9 = 6.1$ m, $N = 2$
(4) Cost = 13,954.4 \$/year
(5) Energy Inputs = 152,320.0 kW-h/year
(6) Grain Damage = 2.75 %/year

With the same procedure, the optimum solutions are obtained for other systems. Table 2 presents the optimum system sizes and number of drying, dryeration and storage bins for six drying systems. Also, it shows the annual drying and storage costs in dollars per year, energy inputs in kW-h per year, and damage percentage in percent per year for 1,762 m^3 harvesting volume.

From the results of optimum systems (Table 2), batch-in-bin drying with stirrer is selected as the best system among six drying and storage systems examined since it has the minimum system cost, 13,954.4 \$/year.

IV. Conclusions

The example problem was formulated and solved for the optimum systems of rough rice drying and storage system of 1,762 m^3 harvest volume by the application of NGP. The following conclusions may be drawn from this study:

1. The model systems and mathematical models

developed can be applied to system design MODM problems effectively and efficiently.

2. The system design problems can be formulated for NGP problems, and solved by NEWINGP program without much difficulties.

Table 2. Optimum systems of drying and storage for 1,762m^3 harvest volume

System parameters		Drying and storage systems					
		NA	NASH	LAY	BIB	BIBS	COM[1]
Drying bin	Diameter, m	13.7	13.7	14.6	9.1	5.5	6.4
	Eave height, m	4.6	4.6	5.5	4.6	3.4	3.4
	Bed depth, m	2.4	2.4	5.3	0.7	1.9	2.7
Dryeration bin	Diameter, m				4.6	4.6	
	Eave height, m				5.5	5.5	
	Bed depth, m				5.4	5.4	
Storage bin	Diameter, m				13.7	13.7	9.1
	Eave height, m				6.7	6.7	4.6
	Bed depth, m				6.1	6.1	3.2
Number of bin*,	K/M/N	5	5	2	2/1/2	2/1/2	1/8
Drying and storage cost,	$/year	19104.6	18029.0	14939.0	15264.9	13954.4	25734.7
Energy input,	kW-h/year	99884.1	77427.1	138617.5	211815.4	152631.0	177258.1
Grain damage percentage,	%/year	3.15	3.80	5.01	3.44	2.75	2.95

* K = Number of drying bin
M = Number of dryeration bin
N = Number of storage bin

COM = Combination drying system

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學 會 廣 告

◎ 第9次 定期 總會

本 學會 第9次 定期 總會 및 세미나 開催日程이 아래와 같이 決定되었읍니다. 이번 總會에서는 會則에 따라 會長團 選擧가 있읍니다. 會員 여러분의 빠짐없는 參席을 바랍니다.

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