벼 調製 및 貯藏시스템의 最適化를 위한 非線型 골 프로그래밍(Ⅰ)

Nonlinear Goal Programming for Optimizing Rice Conditioning and Storage Systems : Part Ⅰ…Modeling

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摘 要

Nonlinear Goal Programming(NGP)이 Multiple Objective Decision Making(MODM) 問題를 適正化 할 수 있는 方法으로 紹介가 되었다. 그리고 6가지의 벼 調製 및 貯藏施設을 分析한 후, NGP에 依하여 適正施設 設計를 하기 위하여 Model Systems를 開發하고 그에 依하여 MODM의 數學的 模型을 開發하였다.

1. Introduction

Since there are many alternative systems for handling, drying and storage of rough rice and most of them are mechanized in the U.S.A., it is not easy to select an economical system which is the best suited for those farmers. Hence, we need a quantitative and qualitative way of comparing the alternative systems. To fulfill this goal, mathematical modeling and optimum techniques may be necessary. But, there are several objectives to be satisfied in rice post-harvest systems such as minimum costs, minimum energy input, minimum grain damage or losses, and minimum labor requirement, etc. These objectives are subjected to farm and/or social characteristics. Therefore, the Multiple Objective Decision Making (MODM) method should be used for the mathematical modeling and optimization of rice postharvest systems.

For the mathematical modeling, several rough rice handling, drying and storage systems were analyzed. Also, price lists of machinery and equipment for those systems, obtained from more than 20 manufacturers in the U.S.A., were analyzed.

2. Review of Literature

In this section some of the applications of systems engineering and operations research techniques to problems of machinery selection and simulation of grain harvesting and drying systems were reviewed. Also, several sources of literature of rice post-harvest systems and losses of rice are reviewed for further analysis of those systems.

1) Machinery Selection by Mathematical Modeling

Several researchers developed mathematical models and tried to select the optimum or the minimum machinery systems for grain harvesting, handling, drying, and storage.

Carpenter and Brooker (1972) developed a model which would determine the minimum cost harvesting, drying and storage system for corn growing operations of various size. The model provides a means of evaluating the effect of the size and type of equipment used in the system by simulating the operation of alternative machine systems on a digital computer.

Bridges (1974) developed a computer model for evaluating selected methods of corn harvesting,

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handling, drying and storage systems. His program can present an economical ranking of the costs of the feasible systems considered.

Bridges et al. (1979) developed a computer simulation model based on Bridges (1974) for selection of least-cost grain drying and storage facilities. The flow network described by that model contained a total of 60 combinations of hauling, handling, drying and storage, and a ranked order with regard to cost for alternative methods of those systems of grain was presented as the outputs.

Chang et al. (1979) developed a grain dryer selection model. In this model, they analyzed drying costs for five drying systems and suggested optimized drying systems with dryer capacity for shelled corn drying.

Even though we have to consider various aspects in selecting an optimum or least cost system for grain handling, drying and storage, these studies mentioned above only satisfied one objective, system costs.

Many investigators have applied operations research or systems engineering techniques for problems of machinery system selection. Among those techniques linear programming, network analysis, probabilistic model, dynamic programming, queueing models, inventory models, simulation and nonlinear programming were used. But, Multiple Objective Decision Making (MODM) method has not been used for design or selection problems of machinery systems, so far.

2) Grain Handling, Drying and Storage Systems

Rice handling, drying and storage systems are discussed in Houston (1972), Luh (1980) and USDA (1973). They presented the drying methods and storage technology of rough rice.

Bern et al. (1979) carried out eight tests to define effects of auger stirring on the airflow resistance and bulk density of wet and dry shelled corn placed in a bin by gravity or by spreader. They developed a stirring effect multiplier for Shedd's curve. It was 0.5 for wet corn placed by spreader.

Steffe et al. (1979) made tests to determine the minimum tempering time required in the multipass drying of high-moisture rice. Also Wasserman et al. (1964) made similar tests. Their data indicate that 4 hours tempering period may be adequate if the rice is tempered at 40.6°C.

Midwest Plan Service (1977) gives a good planning guide for assembling equipment into workable systems. It includes a materials-flow concept, farm materials flow, evaluating storage methods, and system patterns of grain handling, drying and storage.

Behlen Planning Manual (1977) presents general guidelines in planning a grain system and specific application guide in design of grain drying, handling and storage systems.

3) Grain Damage by Handling, Drying and Storage

Grain damage is related to methods and technology of handling, drying and storage. Rice cracking structurally weakens the kernel making it more susceptible to breakage during milling and handling operations. The economic consequence of this is significant because the value of broken rice is much less than that of whole rice. Cracked rise is also more susceptible to insect infestation. Cracking has the added limitation that it may reduce the viability of the seed rice (Luh, 1980).

The characteristics and mechanism of rice cracking has been studied by many researchers. Henderson (1954) concluded in his studies with short grain rice that cracking during fast drying was due to an increase in temperature rather than a decrease in moisture in portions near the surface of the kernel. Kunze and Hall (1965) found that the degree of cracking was dependent on the magnitude of change in relative humidity. They hypothesized that adsorptive fissures were caused when external cells expanded by adsorbing moisture and produced compressive stresses in surface layers. Rhind (1962) indicated that moisture changes in rice resulted in unequal vaolumetric change which induced internal stresses. A similar conclusion was reached by

Kunze and Choudhury (1972).

Rice cracking may occur in the field, in bins holding freshly combined rice, and in certain type of dryers ahead of the drying front (Kunze and Prasad, 1978).

A number of authors have made recommendations to reduce cracking caused by drying. Arora et al. (1973) concluded that a temperature difference larger than 43.0°C between drying air and rice kernels might result in serious cracking and suggested that the drying air temperature be kept below 53.0°C. And they developed a relationship for broken kernels versus drying air temperature for rice. Henderson (1954) made the following recommendations to minimize cracking and to achieve the highest head yields: (1) harvest at a high moisture content, (2) dry at as low a temperature as possible, (3) use as many stages as convenient, and (4) use a gentle milling procedure.

Grain breakage caused by commercial handling methods was studied by Foster and Holman (1973). They made drop tests, grain-thrower test, bucket elevator tests, and tests of effect of repeated handling on breakage for several grains. Also they developed a relationship between grain velocity and breakage. In the bucket elevator test, there was no difference in the breakage at the two elevator speeds tested, and feeding the elevator on the down leg averaged 0.2 percent less breakage than feeding on the up leg.

Sands and Hall (1971) conducted laboratory tests to find out how much damage to shelled corn is contributed by the screw conveyor at different screw speeds, flow rates, and inclinations. Their results showed that less grain damage can be produced by operation at full capacity and low turning speed.

3. Objectives

The objectives of this study were to:

1. Introduce the multiple objective decision making (MODM) method; nonlinear goal programming for design or selection problems of agricultural systems.
2. Analyze the rough rice handling, drying and storage systems.
3. Develop model systems of rough rice handling, drying and storage systems.
4. Develop a mathematical model representing the whole systems with multiple objectives systems constraints.

4. Multiple Objective Decision Making (MODM)

Decision making is the process of selecting a possible course of action from all the available alternatives. In almost all decision making problems, criteria for judging the alternatives are multiple and conflicting with each other. In many such problems, the decision maker (DM) wants to attain more than one goal or objective in selecting the course of action while satisfying the constraints dictated by processes, resources, and capacities. Another characteristic of these problems is that the objectives may be noncommensurable. Mathematically, these problems can be represented as:

$$\begin{aligned} &\text{Max } [f_1(\underline{x}), f_2(\underline{x}), \dots, f_k(\underline{x})] \\ &\text{subject to: } g_i(\underline{x}) \leq 0 \quad i = 1, \dots, m \end{aligned} \qquad (1)$$

where x is an n dimensional decision variable vector. The problem consists of n decision variables, m constraints and k objectives. Any or all of the functions may be nonlinear. In the literature this problem is often referred to as a vector maximum problem (VMP) (Hwang et al., 1979). Multiple Objective Decision Making (MODM) is commonly used for a design problem to find the best alternative. In this process the designer has to develop a set of quantifiable objectives and well-defined constraints under the consideration of various alternatives. Then MODM can be used to get the best alternative through the process of obtaining some trade-off information, implicit or explicit, between the objectives. Most of the design problems of post-harvest systems have the common characteristics of a MODM problem. Therefore, this method will be used as an optimization technique for design of rough rice post-harvest systems. Hwang et al. (1979) present a state-of-the-art survey of MODM methods and applications. Also Paidy (1979) developed an iterative method which can handle the nonlinear goal programming problem.

Most of the design problems of post-harvest systems have the common characteristics of a MODM problem. There are multiple conflicting objectives in system design problems of rough rice drying and storage systems such as minimum cost of systems, minimum energy inputs, and minimum grain damage and losses. For example, those countries which can not produce the energy sources or have an energy shortage problem, will put the minimum energy inputs as a primary goal with a sacrificing of the minimum systems costs and/or minimum grain losses. But, those who are suffering food shortage problems, will emphasize the minimum grain losses for a long-term strategy, even though it requires more cost and/or more energy inputs. Incidentally, most individual farmers seek the maximum profits. Consequently, minimum energy inputs and minimum grain losses may be goals of countries for a long-term strategy, and minimum cost of systems can be an objective of farmers. This is the reason why we need a decision analysis model which can handle the multiple objective decision making problem.

5. Nonlinear Goal Programming (NGP)

There are many methods of multiple objective decision making according to Hwang et al. (1979). Among them a formal decision analysis that is capable of handling multiple conflicting goals through the use of priorities may be a new frontier of management science.

The goal programming approach appears to be an appropriate, powerful, and flexible technique for decision analysis of the troubled modern decision maker who is burdened with achieving multiple conflicting objectives under complex system constraints. Goal programming allows a simultaneous solution to a system of complex multiple objectives. Goal programming is capable of handling decision problems that deal with a single goal with multiple subgoals, as well as problems with multiple goals and multiple subgoals. The goal-programming approach utilizes an ordinal hierarchy among conflicting multiple goals so that the low-order goals are considered only after the higher-order goals are satisfied or have reached the desired limit (Lee, 1972).

A number of assumptions are necessary in the development of any viable model. The goal program and extended goal program models are no exception. In many ways, however, these models are less constrained by assumptions than the more traditional models (Ignizio, 1976).

There are two key assumptions for the goal program. One is that the analyst, working with the actual decision maker, can establish preemptive priorities for each objective or groups of objectives. The highest priority is indicated by a_1, the next highest by a_2, and so forth. The notion of preemptive priorities holds that a_1, is preferred to a_2 regardless of any multiplier associated with a_2. A second assumption is that all decision variables are non-negative. This assumption is necessary since the solution method employed can only consider non-negative variables. At first, these assumptions sound quite restrictive, but, in practice many problems can be shown to be adaptable to those assumptions and to be circumvented by a simple approach.

According to Hwang et al. (1979), the complete Nonlinear Goal Programming model formulation can be given by:

$$\left.\begin{array}{l}
\text{To find } \underline{x} = (x_1, x_2, \ldots, x_n) \text{ so as to} \\
\min \underline{a} = a_1(\underline{d}^-, \underline{d}^+), a_2(\underline{d}^-, \underline{d}^+), \ldots, a_j(\underline{d}^-, \underline{d}^+) \\
\text{subject to } g_i(x) + d_i^- - d_i^+ = c_i, \ i = 1, \ldots, m \\
\quad f_i(\underline{x}) + d_{m+i}^- - d_{m+i}^+ = b_i, \ i = 1, \ldots k \\
\quad \underline{d}^-, \underline{d}^+ \geq 0, \ d_i^- = 0, V_i
\end{array}\right\} \quad (2)$$

where

x = decision variable
$\underline{x}$ = n dimensional decision variable vector
a = achievement function
$\underline{a}$ = achievement function vector
d_i^- = the under-achievement
d_i^+ = the over-cahievement
$g_i(\underline{x})$ = constraint function
$f_i(\underline{x})$ = objective function

If any of $f_i(\underline{x})$ and $g_i(\underline{x})$ functions in equation (2) are nonlinear, equation (2) becomes a nonlinear goal programming problem.

Each achievement function, $a_j(\underline{d}^-, \underline{d}^+)$, is a linear function of the appropriate deviational variables. Each deviational variable is determined independently from the corresponding constraint equation as follows:

$$\left.\begin{aligned} d_i^- &= d_i^- \text{ if } d_i^- \geq 0 \\ &\quad\; 0 \text{ if } d_i^- \leq 0 \\ \text{where}\quad d_i^- &= c_i - g_i(\underline{x}) \\ d_i^- &= b_i - f_i(\underline{x}) \end{aligned}\right\} \qquad (3)$$

similarly,

$$\left.\begin{aligned} d_i^+ &= d_i^+ \text{ if } d_i^+ \geq 0 \\ &\quad\; 0 \text{ if } d_i^+ < 0 \\ \text{where}\quad d_i^+ &= g_i(\underline{x}) - c_i \\ \text{or}\quad d_i^+ &= f_i(\underline{x}) - b_i \end{aligned}\right\} \qquad (4)$$

Notice that in the process of determining each deviational variable, the corresponding absolute or goal constraint, which is a function of the decision variables, $x = (x_1, x_2, ..., x_n)$, is utilized so that the constraints equation in (2) are no longer the constraints to the minimization problem in the sense of constraints in single objective nonlinear programming problems (Hwang et al., 1979).

Minimization of $f(\underline{x})$ can be viewed as satisfying a goal $f(\underline{x}) \leq b$ as much as possible where b is an arbitrary but unachievable value (lower than the expected minimum). The achievement function a is to minimize the positive deviational variable of equation (2), d_{m+1}^+. Similarly maximization of $f(\underline{x})$ can be done. (Paidy, 1979)

The procedure to select negative and/or positive deviational variables corresponding to each constraints is as follows:

Constraints to be satisfied	Variables to be minimized
(a) $g_i(\underline{x}) \geq c_i$	d_i^-
(b) $g_i(\underline{x}) \leq c_i$	d_i^+
(c) $g_i(\underline{x}) = c_i$	$d_i^- + d_i^+$

6. Procedures of Modeling

The following steps were taken for modeling in this study:

1) Analysis of handling, drying, and storage systems of rice production in the United States.
2) Collection of equipment catalogs including pri-

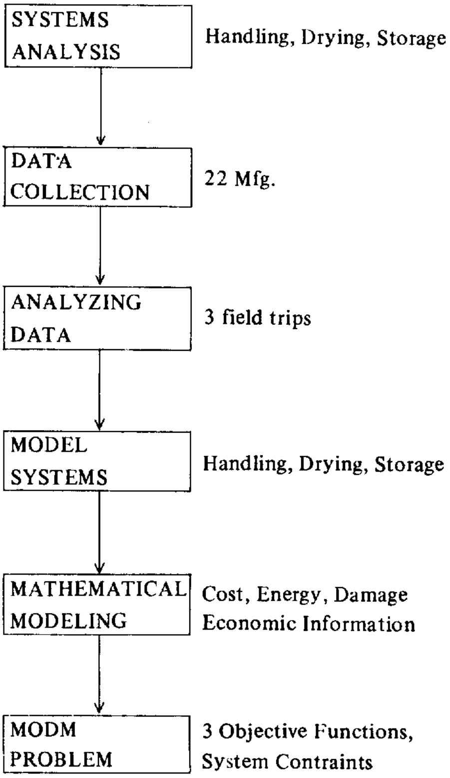

Fig. 1. Procedures of modeling.

ces of equipment and systems of grain receiving, loading, unloading, drying, and storage.

3) Analysis of systems and making assumptions for models. In order to analyze rice handling, drying, and storage systems, several references were reviewed and three field trips were taken to rice growing areas in the United States.
4) Developing model systems for drying, storage and handling based on the systems analysis.
5) Mathematical modeling for cost functions, energy functions and grain damage functions, which is incorporated with the economic information, assumptions and model systems developed to form a multiple objective decision making problem.

Figure 1 shows the procedures of modeling in diagram.

7. Systems Analysis

The first step for mathematical modeling is systems analysis and making some assumptions. For systems analysis, rice handling, drying and storage systems were analyzed and data were collected. Also a few assumptions for systems and subsystems were made to develop models.

Figure 2 shows the systems considered of rough rice handling, drying and storage for on-farm installation. Table 1 presents a summary of equipment and their manufacturers used in the analysis and the effective dates of price quotation. Cost comparisons in the analysis were made between systems and not between manufacturers.

Catalogs obtained from manufacturers listed on Table 1, and other planning guides were carefully studied for grain handling, drying, and storage system. Table 2 shows the handling systems. The grain handling systems consist of receiving, loading and unloading systems.

There are four methods of receiving system: steel hopper for transport auger: swinging hopper

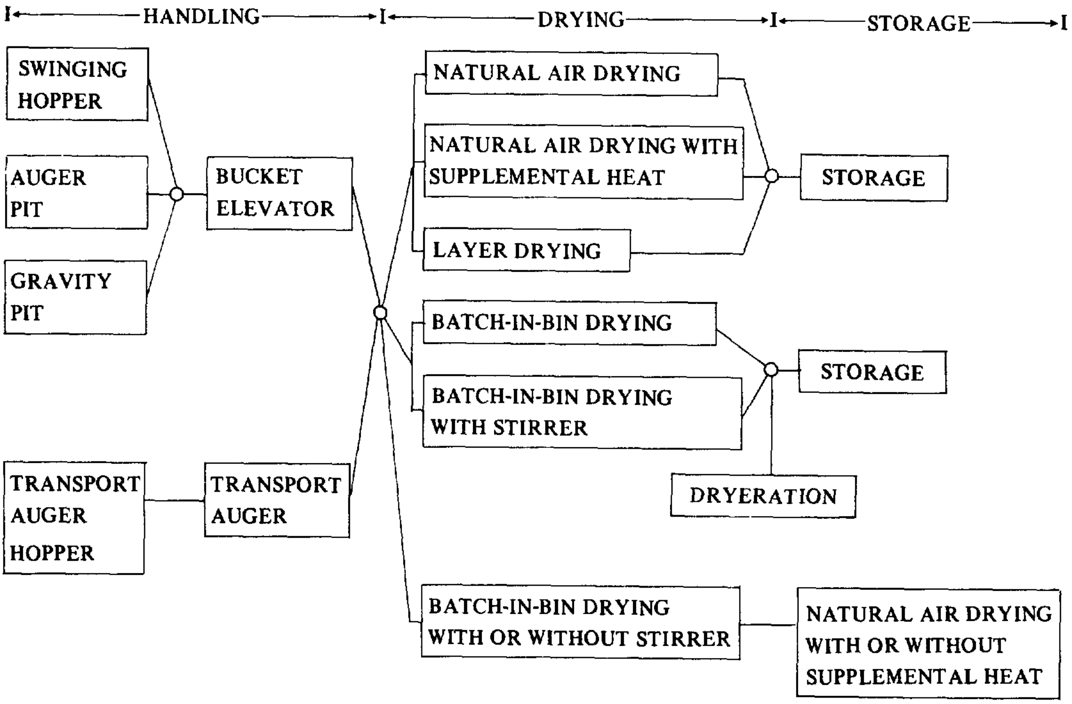

Fig. 2. Rough Rice Handling, Drying and Storage Systems for On-Farm Installation.

Table 1. Sources of Systems Catalog and Price Quotation Dates

Manufacturer and Equipment	Effective Date
1. Beard Industries, Frankfort, IN	———
Grain dryer	
2. Behlen Mfg. Co., Columbus, NB	———
Grain dryer	
Grain bin	
Bucket elevators	
3. Bush Hog/Eaton, Hutchinson, KS	Jan. 1, 1980
Grain bin	
4. Butler Mfg. Co., Kansas City, KS	Nov. 16, 1979
Grain bin	
Grain dryer	
Aeration accessaries	
5. Caldwell Mfg. Co., Kearney, NB	March 18, 1980
Aeration systems	
Grain bin accessories	
6. Cardinal Div., LML Corp., Columbia City, IN	April 1, 1980
Bucket elevator	
Unloading equipment	
7. Clay Equip. Corp., Morton, IL	———
Bucket elevator	
8. Combustion Equip. Co., Kansas City, MO	Aug. 18, 1980
Fan and heater	
9. Farm Fans, Inc., Indianapolis, IN	Nov. 16, 1979
Grain dryer	
Aeration accessories	
Grain spreader	
Fan and heater	
10. Gilmore & Tatge Mfg. Co., Inc., Clay Center, KS	Jan. 1, 1980
Transport auger	
Grain dryer	
Conveying systems	
11. Hutchinson Div., Lear Siegler, Inc., Clay Center, KS	May 5, 1980
Grain augers	
Bucket elevator	
12. Long Mfg. N.C. Inc., Tarboro, N.C.	———
Grain bin	
Aeration equipment	
13. MJM Enterprises, Inc., Manning, LA	Feb. 1, 1980

Table 1. — Continued

Manufacturer and Equipment	Effective Date
Grain handling and feeding equipment	
14. M&W Gear, Gibson City, IL	Dec. 3, 1979
Grain dryer	
15. Nebraska Engineering Co., Omaha, NB	April 1, 1980
Grain unloading equipment	
Grain auger	
Bucket elevator	
Grain spreader	
16. Portable Elevator Div., Dynamics Corp. of America, Bloomington, IL	May 1, 1980
Elevator and conveyor	
17. Stormor, Fremont, NB	——
Grain bin	
Grain dryer	
Grain unloading equipment	
18. Sukup Mfg. Co., Sheffield, IA	Dec. 1, 1979
Grain bin and stirrer	
Aeration system	
Grain spreader	
19. Sweet Mfg. Co., Springfield, OH	Jan. 1, 1980
Bucket elevator	
20. Westeel Incorp., Fargo, ND	July 25, 1980
Grain bin	
Unloading equipment	
Aeration system	
21. Westgo, West Fargo, ND	——
Auger conveyor	
Bin unloading systems	
22. Grainger's, Topeka, KS	Summer 1980
Electric motor	

with motor: auger pit with motor and pit structure: and gravity pit with pit structure. The last three methods are considered for bucket elevator. Among these, the auger pit and gravity pit were analyzed in detail and a few assumptions were made for pit design by Chang (1981).

The drying systems and storage systems analyzed were summarized in Table 3. Among drying systems, the grain bin for drying, the perforated floor and steel substructure, the fan and motor for drying, the transition duct, the humidistat, the thermostat, and the static pressure gauge are common to all drying systems. The stirrer and motor, and the perforated bin-wall liner set are required for the drying system of batch-in-bin drying with stirrer. The diameter of the grain bin ranges from 4.6 meters

Table 2. Grain Handling Systems for Receiving, Loading and Unloading

Receiving	Loading	Unloading
1. Steel hopper	1. Transport auger	1. Sweep auger
2. Swinging hopper	2. Motor for transport auger	2. Motor for sweep auger
3. Motor for swinging hopper	3. Swivel arc axle kit	3. Tube and sump
4. Auger pit	4. Roof auger	4. Horizontal unloading auger
5. Motor for auger pit	5. Overhead distributing auger	5. Motor for unloading auger
6. Pit structure	6. Motor for roof auger	6. 25° bin unloader
7. Gravity pit	7. Motor for overhead distributing auger	7. Return unloading auger
	8. Bucket elevator head, boot & leg	8. Motor for return unloading auger
	9. Motor for bucket elevator head	
	10. Distributor	
	11. Cleaner	
	12. Downspouting	
	13. Spouting trussing kit	
	14. Grain spreader	

Table 3. Grain Drying and Storage Systems

Drying Systems	Storage Systems
1. Grain bin for drying	1. Grain bin for storage
2. Grain bin for dryeration	2. Perforated floor and steel substructure
3. Perforated floor and steel substructure	3. Fan and motor for aeration
4. Fan and motor for drying	4. Humidistat
5. Fan and motor for dryeration	5. Thermostat
6. Transition duct	6. Miscellaneous
7. Humidistat	
8. Thermostat	
9. Static pressure gauge	
10. Gas heater	
11. Electric heater	
12. Stirrer and motor	
13. Perforated bin-wall liner	
14. Miscellaneous	

to 27.4 meters in the grain bins catalogs, but it is assumed to be ranged from 4.6 meters to 14.6 meters in this study. The ranges of eave heights are 3.4 meters to 7.9 meters (this study assumes a grain bin height ranging from four to nine rings). A ring height of 0.81 meters was used by most manufacturers.

In the study of Chang (1981), mathematical models describing the size and capacity of equipment were developed, and the ranges of system parameters and some assumptions were made. Therefore, the above works were used in this study.

8. Results

1) Model Systems

Model systems of rice handling, drying and storage were developed based on systems analysis and assumptions. Since there are various systems and accessories, it is not possible to develop a mathematical model without model systems which are typical and essential for each system. Table 4 through Table 8 show the model systems for rough rice receiving, loading, unloading, drying, and storage systems. In the tables, the following symbols were used to describe the systems and number of

Table 4. Model Systems of Drying

No. of			No. of Subsystem						Consideration	
System		Subsystem Description	NA	NAAG	LAY	BIB	BIBS	COM	Energy	Grain Damage
1	1	Grain bin for drying	N	N	N	K	K	K+N		X
	2	Grain bin for dryeratio				M	M			
	3	Perforated floor and steel substructure	N	N	N	K+M	K+M	K+N		
	4	Fan and motor for drying	N	N	N	K	K	K+N	X	
	5	Fan and motor for dryeration				M	M		X	X
	6	Transition duct	N	N	N	K	K	K+N		
	7	Humidistat	N	N	N	K	K	K+N		
	8	Thermostat	1*	N	N	K	K	K+1		
	9	Static pressure gauge	1	1	1	1	1	1		
	10	Gas heater		N	N	K	K	K	X	X
	11	Stirrer and motor					K	K	X	
	12	Perforated bin-wall liner set					K	K		

* 1 = No. of subsystem (one)

Table 5. Model Systems of Storage *

No. of			No. of Subsystems						Consideration	
System		Subsystem Description	NA	NASH	LAY	BIB	BIBS	COM	Energy	Grain Damage
2	1	Grain bin for storage				N	N			
	2	Perforated floor and steel substructure				N	N			
	3	Fan and motor for aeration	N	N	N	K+N	K+N	K+N	X	
	4	Humidistat				M+N	M+N			
	5	Thermostat				1	1			

* 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
COM = Combination drying

subsystems.

NA = Natural air drying system

NASH = Natural air drying system with supplemental heat

LAY = Layer drying system

BIB = Batch-in-bin drying system

BIBS = Batch-in-bin drying system with stirrer

COM = Combination drying system

K = the number of the grain bin for batch drying

M = the number of the grain bin for

Table 6. Model Systems of Receiving in Handling

No. of			No. of Subsystems				Consideration	
			In-Bin Systems		Batch-In-Bin Systems		Energy	Grain Damage
System		Subsystem Description	TA*	BE**	TA	BE		
3	1	Steel hopper	NT***		NT			
	2	Swinging hopper		1				X
	3	Motor for swinging hopper		1			X	
	4	Auger pit				1		X
	5	Motor for auger pit				1	X	
	6	Pit structure				1		
	7	Gravity pit				1		

* TA = Transport auger system

** BE = Bucket elevator system

*** NT = Number of transport auger

Table 7. Model Systems of Loading in Handling

No. of			No. of Subsystems				Consideration	
			In-Bin System		Batch-In-Bin System		Energy	Grain Damage
System		Subsystem Description	TA	BE	TA	BE		
4	1	Transport auger	1		NT			X
	2	Motor for transport auger	1		NT		X	
	3	Swivel arc axle kit	1		NT			
	4	Roof auger	N		N			X
	5	Motor for roof auger	N		N		X	
	6	Overhead distribution auger	X	X	X	X		X
	7	Motor for overhead distributing auger	X	X	X		X	
	8	Bucket elevator head, boot & leg		1		1		
	9	Motor for bucket elevator head		1		1	X	
	10	Distributor		1		1		
	11	Cleaner		1		1		
	12	Downspouting		X		X		
	13	Spouting trussing kit		1		1		
	14	Grain spreader	N	N	K+M+N	K+M+N	X	

Table 8. Model Systems of Unloading in Handling

No. of System		Subsystem Description	No. of Subsystems				Consideration	
			In-Bin System		Batch-In-Bin System		Energy	Grain Damage
			TA	BE	TA	BE		
5	1	Sweep Auger	1	1	K+M+1	K+M+N*		
	2	Motor for sweep auger	1	1	K+M+1	K+M+N	X**	
	3	Tube and sump	N	N	K+M+N	K+M+N		
	4	Horizontal unloading auger	1	1	K+M+1	K+M+N		X
	5	Motor for unloading auger	1	1	K+M+1	K+M+N	X	
	6	25° Bin unloader	1					X
	7	Return unloading auger	X	X	X	X		X
	8	Motor for return unloading auger	X	X	X	X	X	

* K = Number of batch-in-bin drying bin
M = Number of dryeration bin
N = Number of storage bin
**X = Mark for the factor to be considered in mathematical model

dryeration
N = the number of the grain bin for in-bin system
NT = the number of the transport auger

Also, these tables provide the information for consideration of the energy and the grain damage model. If a subsystem should be considered for an energy model or a grain damage model, X mark is made on the tables.

Model systems of drying and storage were developed for six drying methods. Model systems for handling (receiving, loading and unloading) were developed for in-bin drying systems and batch-in-bin drying systems, which were handled by transport auger systems and bucket elevator systems, respectively.

Some of the subsystems were expressed by X mark because they are dependent on the drying systems and layouts.

The models of batch-in-bin systems are developed so that the grain bins of batch-in-bin drying will be used for grain storage after all the grain is dried. Also, the dryeration bin is to be used for grain storage when drying is over.

The combination drying system is designed for batch-in-bin drying with a stirrer and natural air drying. The drying bins are supposed to be used for storage when the drying process is finished.

The numbers of the system were made in series for mathematical model development. The system numbering consists of two numbers. The first is for the systems and the second is for the subsystems.

The main purpose of the development of the model systems is to present the system concisely so that time and effort can be saved in the selection and design of the systems. Therefore, the mathematical model will be developed in conjunction with these model systems.

2) Mathematical Modeling for Systems

There are many alternative systems for handling, drying and storage of rough rice as shown in Figure 2. We realize that it is not easy to select an economical system which is the best suited for each farm or country. Therefore, we need a quantitative and qualitative way of comparing the alternative systems. To fulfill this goal, mathematical modeling and optimization techniques are necessary.

But, there are several objectives to be satisfied in rice post-production systems such as the following:

1. Minimum costs of handling, drying and storage
2. Minimum energy inputs
3. Minimum grain damage or losses

These objectives conflict with each other, depending on the farm situation or social characteristics. For this reason, the systems should be modeled with multiple objectives and optimized by multiple objective decision making (MODM) method.

The mathematical models were developed for the cost of equipment, energy requirements, grain damage and general model. The purpose of mathematical modeling is to develop multiple objective functions with constraints of systems.

The costs of the subsystem of model systems were developed in the function of system parameters. Most of these relationships were developed by multiple regression analysis. The price lists were obtained from the manufacturers listed on Table 1.

The modeling of energy covers the horsepower requirement of the fan for drying and aeration, the heat requirement of gas heater for drying, the horsepower requirement for conveying systems and stirring devices. The labor requirement was also discussed in this modeling.

There are several sources for rough rice damage in handling, drying and storage. But the following two are the most significant sources in damage or broken kernel of rice.

1. Rice broken damage percentage by drying technique and drying air temperature.

$$\text{DAMAGE} = a(0.093 \times \text{TEMP} - 4.29) \qquad (5)$$

where

DAMAGE = rice damage percentage, percent

a = coefficient of drying technique, decimals
In-bin drying system: 1.0
Batch-in-bin drying with dryeration: 0.6
Batch-in-bin drying with stirrer, with dryeration: 0.5
Combination drying: 0.75

TEMP = temperature of drying air, °F

This equation was developed from the data of Arora (1973) and Henderson (1954) by multiple regression analysis. The R square value was 0.99.

2. Broken and cracked kernel damage percentage by screw conveyors.

$$\text{DAMAGE} = 0.36 - 2.56 \times 10^{-6} \times \text{AUGCAP} + 5.0 \times 10^{-3} \times \text{LN} - 2.70 \times 10^{-8} \times \text{AUGCAP} \times \text{LN} \quad (6)$$

were

DAMAGE = broken and cracked kernel percentage, percent

AUGCAP = capacity of auger, cu. meters per hour

LN = length of auger, meter

This equation was developed from the data of Sands and Hall (1971) by multiple regression method. The R square value is 0.96 for equation (6).

Economic information is essential for this study. Table 9 persents the following information for the drying and storage systems.

1. Expected life, years (Lower et al., 1976 b)
2. Interest, percent (Farmers Home Administration, 1980)
3. Taxes, insurance, percent of list (ASAE Yearbook, 1980)
4. Repair, percent of list (Lower et al., 1976 b)
5. Sum of the percentage of list, percent

The above information tabulated in Table 9 came from the different sources shown in parenthesis. The straight-line method was used for the annual depreciation change without salvage, and all of the costs were expressed as the sum of the percentage of the list price of equipment.

The systems cost is a sum of fixed costs, operating costs and grain damage costs. Fixed costs are those that are usually not directly related to the amount of use. They include depreciation, interest on the investment, taxes, and insurance. Operating costs include the cost of heat, electricity, labor cost and repair cost. Since repair cost was modeled in Table 9 as a percent of list price, it

Table 9. Economic Information of Grain Handling, Drying and Storage Systems

Subsystem	Expected Life (year)	Interest (%)	Taxes, Insurance (% of list)	Repair	Sum of Percentage (% of list)
1. Bin structure	20	10.5	1.25	0.05	11.55
2. Perforated floor and substructure	20	10.5	1.25	0.05	11.55
3. Fan and motor	10	10.5	1.25	1.00	17.50
4. Transition duct	20	10.5	1.25	0.05	11.55
5. Humidistat	5	10.5	1.25	4.00	30.50
6. Thermostat	5	10.5	1.25	4.00	30.50
7. Static pressure gauge	5	10.5	1.25	4.00	30.50
8. Gas heater	10	10.5	1.25	1.00	17.50
9. Stirrer and motor	7	10.5	1.25	2.00	22.79
10. Perforated bin-wall liner	20	10.5	1.25	0.05	11.55
11. Steel hopper	10	10.5	1.25	0.05	16.55
12. Swinging hopper	10	10.5	1.25	0.05	16.55
13. Auger pit	10	10.5	1.25	1.00	17.50
14. Gravity pit	20	10.5	1.25	0.05	11.55
15. Transport auger	7	10.5	1.25	4.00	24.79
16. Electric motor	10	10.5	1.25	1.00	17.50
17. Swivel arc axle kit	7	10.5	1.25	4.00	24.79
18. Roof auger	7	10.5	1.25	2.00	22.79
19. Overhead distributing auger	7	10.5	1.25	2.00	22.79
20. Buket elevator	20	10.5	1.25	0.05	11.55
21. Distributor	20	10.5	1.25	0.10	11.60
22. Cleaner	20	10.5	1.25	0.50	12.00
23. Downspouting	20	10.5	1.25	0.02	11.52
24. Spouting trussing kit	10	10.5	1.25	1.00	17.50
25. Grain spreader	10	10.5	1.25	1.00	17.50
26. Sweep auger	7	10.5	1.25	2.00	22.79
27. Tube and sump	20	10.5	1.25	0.05	11.55
28. Horizontal unloading auger	7	10.5	1.25	2.00	22.79
29. 15° Bin unloader	7	10.5	1.25	2.00	22.79
30. Return unloading auger	7	10.5	1.25	2.00	22.79

was included in fixed cost percentage in this study. Grain damage costs are caused by reduction of grain quality or grade. These three kinds of costs are expressed by the following equations:

$$\text{Fixed Costs (\$/year)} = \sum_{i=1}^{i=k} \sum_{j=1}^{j=r} \left(\frac{FC\%}{100} \times P_{ij} \times K_{ij}\right) \qquad (7)$$

$$\text{Operating Costs(\$/Year)} = \frac{HT}{CE} \times OT_h \times P_f \times K) + 0.7457\, P_e \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} (EL_{ij} \times OT_{e_{ij}} \times K_{ij}) + P_m \sum_{i=1}^{i=3} (L_i \times OT_{m_j}) \qquad (8)$$

Grain Damage Costs (\$/year) = 0.01V x

$$P_g \sum_{i=1}^{i=m'} \sum_{j=1}^{j=n'} GD_{ij} \qquad (9)$$

The energy equipment, for the sum of energy for the heater, electricity usage and labor. Bowers et al. (1975) suggest that one average man's power can be estimated as 0.25 horsepower for engineering applications. The total grain damage percentage is the sum of the damage percentage caused by drying and handling systems. Then, grain damage costs are calculated by the product of the total grain damage percentage, grain volume and grain price.

The energy inputs for system is:

$$\text{Energy Inputs (kW.h/year)} = (HT \times OT_h \times K/CE)$$

$$+(0.7457 \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} EL_{ij} \times OT_{e_{ij}} \times K_{ij})$$

$$+(0.1864 \sum_{i=1}^{i=3} L_i \times OT_{m_i}) \qquad (10)$$

Grain damage percentage is:

$$\text{Grain Damage (\%/year)} = \sum_{i=1}^{i=m'} \sum_{j=1}^{j=n'} GD_{ij} \qquad (11)$$

where

FC% = fixed costs percentage, percent

P_{ij} = price of equipment, dollars

K = number of equipment or subsystem, integer

HT = heat requirement, kW

CE = combustion efficiency of fuel, decimals

OT = operational time, hour

subscript, h: heater

e: electricity

m: labor

P_f = price of fuel, dollars per kW.h

P_e = price of electricity, dollars per kW.h

P_m = price of labor, dollars per hour

P_g = price of grain, dollars per cu. meters

EL = electricity requirement, horsepower

L = number of men for labor, integer

V = annual total volume of grain, cu. meters

GD = grain damage percentage, percent

Therefore, the three objective functions to be considered for optimization are:

Minimize System Cost (\$/year) = equation (7) + equation (8) + equation (9)

Minimize Energy Inputs (kW.h/year) = equation (10)

Minimize Grain Damage (%/year) = equation (11)

The possible system constraints are:

1. Bin diameter
2. Bin eave height
3. Grain bed depth
4. Grain bed depth $\leq$ Bin eave height
5. Fan and motor size
6. Heater size
7. Number of bin
8. Transport auger capacity
9. Transport auger length
10. Bucket elevator capacity
11. Discharge height of bucket elevator
12. Harvesting period
13. Harvesting rate
14. Capacity of unloading auger
15. Amount of investment

9. Conclusions

In order to develop a mathematical model of a rough rice handling, drying, and storage system, various kinds of systems were analyzed and model systems were developed for the different systems. The following conclusions may be drawn from this study.

1. There are four receiving systems, two loading systems, and six drying and storage systems for rough rice handling, drying and storage systems of on-farm installations.
2. The model systems of drying, storage, receiving, loading and unloading of rough rice were developed.
3. Mathematical modelings for system cost, energy inputs, and grain damage were made.
4. A mathematical model of systems was developed

with multiple objectives and system constraints.

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