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SIMULATION OF WEATHER EFFECT MINIMIZATION INVESTMENT: AN APPLICATION TO GRAIN DRYING SYSTEM DESIGN AND MANAGEMENT IN A DEVELOPING REGION

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SIMULATION OF WEATHER EFFECT MINIMIZATION INVESTMENT: AN APPLICATION TO GRAIN DRYING SYSTEM DESIGN AND MANAGEMENT IN A DEVELOPING REGION

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE
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ABSTRACT

The effect of weather on agricultural production and processing is of vital concern to all farmers. Grain drying systems, especially in the developing world, are complex and weather dependent. Because of the large degree of risk due to the random nature of weather, farmers in developing nations have had problems in the adoption of artificial drying.

The centralized grain drying facilities are usually designed without considering adequately the random effects of weather. As a result, most grain drying investments are found to be uneconomical. Efficient design and economic operation can only be achieved through better understanding of all the relevant variables and their interrelationships in the entire drying system. A general simulation model for grain drying (WEGDM) was developed by including the pertinent weather variables, either stochastic or deterministic, into a meaningful analysis. It is built to be general enough to simulate most grain drying systems. The model consists of three major computer programs, namely, Simulation Program for Weather Variables (SPWV); Simulation Program for Grainflow, Drying and Management (SPGDM); and Simulation Program for Financial Analysis (SPFA). The SPWV program

simulates sunny and no-sunny days for grain drying; harvest and no-harvest days; wind and no-wind days for grain harvesting; using Markov Transition Probabilities. The SPGDM program simulates the amount of grain flow, moisture content of the grain and grain losses in various stages of grain handling and processing. The program SPFA is designed to calculate and gather all pertinent cost information into a meaningful economic analysis. The Net Present Value (NPV) of cash flow has been considered as a decision criterion of the model. The main program with 23 subroutines in the FORTRAN 77 language has been designed to make the program flexible and easy to follow. The grain paddy and the Los Banos area of the Philippines were chosen for development and verification of this model.

The application of the model is extensive. Design of a grain processing complex, economic analysis of an existing plant, feasibility study of a grain drying plant and evaluation of alternative drying strategies are the important areas of application of the model.

TABLE OF CONTENTS

Page

Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

Figure Page

LIST OF SYMBOLS

Symbol			Unit
A	=	Critical level of rainfall for determination of sun-no sun day	mm
A_a	=	Cross-sectional area of dryer	m^2
A_b	=	Daily area harvested during peak harvest	ha
A_e	=	Daily area harvested during early harvest	ha
A_{el}	=	Total area to be harvested in an early or a late period in a harvesting season	ha
A_h	=	Total area to be harvested during peak harvest	ha
A_t	=	Daily area harvested in a late harvest	ha
A_1	=	Surface area for sundrying	m^2
A_2	=	Surface area (for sundrying) that can be managed effectively by a single laborer	m^2
A_3	=	Cross-sectional area of storage for wet grain	m^2
A_4	=	Cross-sectional area of storage for	

		dry grain	m^2
a	=	A constant	-
B	=	Critical level of solar radiation for determination of sun-no sun day	$cal/cm^2/day$
B/C	=	Benefit-cost ratio	-
b	=	A constant for a particular grain	-
b_1	=	A constant for a particular grain	-
b_2	=	A constant for a particular grain	-
b_3	=	A constant for a particular grain	-
b_4	=	A constant for a particular grain	-
C	=	Critical level of rainfall for determination of harvest-no harvest day	mm
C_c	=	Capital consumption on facilities and equipment	M*/yr
C_d	=	Energy cost of grain drying per unit volume of grain	M/m^3
C_{ds}	=	Cost of grain drying by sun	M/day
C_{ec}	=	Cost of elevating/conveying the grain	M/day
C_F	=	Total fixed cost of the entire plant	M/yr
C_{fo}	=	Cost of fan operation per unit volume of grain	M/m^3
C_{of}	=	Cost of fan operation	M/day
C_{pa}	=	Specific heat of dry air	kJ/kg^0C
C_{pv}	=	Specific heat of water vapor	kJ/kg^0C

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* Any monetary unit

C_{rf} = Capital recovery factor -

C_{st} = Shelter cost M/yr

CT = Corporate tax decimal

c = A constant for a particular grain -

c_1 = A constant for a particular grain -

c_2 = A constant for a particular grain -

c_3 = A constant for a particular grain -

D = Critical level of solar radiation for determination of harvest-no harvest day $cal/cm^2/day$

D_a = Total number of harvesting days during peak harvest day

D_d = Number of dimensionless depth units to the point where M_a is computed -

D_e = Yearly depreciation on facilities and equipment M/yr

D_m = Working days in a late harvest period day

D_n = Working days in an early harvest period day

D_p = Pressure drop through grain per unit depth of grain Pa/m

D_{pr} = Potential optimum drying capacity $m^3/8$ hr

D_r = Drying capacity of the dryer (plant) m^3/t_d hr

D_{sh} = Daily available solar hours hr/day

E = Critical level of wind speed for

		determination of wind-no wind day	km/hr
e_0	=	Overall thermal efficiency of the dryer	decimal
e_1	=	Overall efficiency of fan-motor or fan-engine system	decimal
e_2	=	Overall efficiency of grain conveyor or elevator	decimal
F	=	F-value, a standard parameter used in statistical analysis	-
FC	=	Total fixed cost during entire life of the plant	M
H	=	Time-of-half-response of the grain being dried	hr
H_r	=	Humidity ratio of ambient air	kg/kg
IC	=	Investment cost	M
I_p	=	Insurance payment	M/yr
INF	=	Initial investment in equipment and facilities	M
K	=	Electric power	kW
K_d	=	Thin layer drying constant	hr^{-1}
KFD	=	The number of future bad weather day(s) that farmers may wait for sundrying before they decide to sell their grain to the plant	-
KSD	=	A policy indicator for drying of the	

partially dried grain. KSD = 1 means partially dried grain is dried by the plant. If plant is not available, it is dried finally by sun. KSD = 2 means partially dried grain is dried by natural sundrying. If sun is not available, it is dried finally by the plant. -

KSY = A management indicator for sale of dry grain to the market. KSY = 1 means all dry grain is sold out at the end of each drying season. KSY = 2 means all dry grain is sold out only at the end of each year. -

KWD = A decision indicator for use of weather data. KWD = 1 means historical weather data is used directly. KWD = 2 means historical weather data is used to generate daily temperature and relative humidity of air, using fitted probability distributions. -

L = Life of equipment and facilities yr

L_v = Latent heat of vaporization of moisture in the grain kJ/kg

LAN = Initial land value M

l_m = Height of storage bin m

M = Any monetary unit -

M_a = Average grain moisture content % db

M_c = Moisture content of the grain % db

M_e = Equilibrium moisture content of the grain for initial condition of the air entering the grain % db

M_f = Final safe moisture content of the grain % db

M_0 = Initial moisture content of the grain % db

M_r = Moisture ratio decimal

M_s = Moisture content of the grain after a day of sundrying % db

m = Mass flow rate of drying (heated) air kg/hr

N = Number of simulated year yr

NCF = Net cash flow M

NCF(i) = Net cash flow for the year i M

N_m = Maximum number of successive no sunny days during harvesting seasons of entire simulated period -

NPV = Net present value M

N_s = Number of sequence of no sun today no sun tomorrow during harvesting seasons of entire simulation period -

n = A constant for a particular grain -

P = Purchase price of equipment/facilities M

P_a = Atmospheric pressure Pa

P_e = Power required to elevate/convey the grain kW

P_f = Power required to force air through grain kW/m^3

P_m = Price of an electric motor M

P_s = Saturated vapor pressure at T^0C Pa

P_{sa} = Saturated vapor pressure at $T_a{}^0C$ Pa

P_{sh} = Saturated vapor pressure at $T_h{}^0C$ Pa

PSV = Plant salvage value at the end of Nth year M

PV(NCF)= Present value of net cash flow M

P_v = Vapor pressure Pa

P_1 = Price of energy for grain drying M/unit

P_2 = Price of energy/electricity M/unit

P_3 = Labor price M/hr

P_4 = Price of wet grain at harvest M/m^3

P_5 = Price of dry grain during harvesting season M/m^3

P_6 = Price of dry grain during non-harvesting season M/m^3

Q = Air flow rate through grain m^3/m^2-s

q = A constant for a particular grain -

q_1 = Heat content of energy for

		grain drying	kJ/unit
R	=	Relative humidity of air	decimal
R_a	=	Relative humidity of ambient air	decimal
R_e	=	Relative humidity of exhaust air	decimal
R_h	=	Relative humidity of drying (heated) air	decimal
RH	=	Relative humidity of air	%
R^2	=	R-square, a standard parameter used in statistical analysis	-
r	=	Interest rate	decimal
S	=	Salvage value of equipment/facilities	M
S_L	=	Safe storage life of grain	day
$S_{y.x}$	=	Standard error of estimate	-
T	=	Air temperature	^{0}C
T_A	=	Mean total crop area within the service area of the plant	ha
T_a	=	Ambient air temperature	^{0}C
T_c	=	Temperature increment above ambient	^{0}C
TC	=	Total cost	M/yr
T_e	=	Equilibrium temperature; temperature at which air would be in equilibrium with the grain at its initial moisture after the air has cooled adiabatically	^{0}C
TDD	=	Total daily drying capacity of the	

dryers presently used within the service area of the plant m^3/day

T_g = Grain temperature ^0C

T_h = Drying (heated) air temperature ^0C

T_p = Property tax M/yr

TR = Total revenue M/yr

T_s = Surface temperature where grain is to be dried by sun ^0C

T_{st} = Sales tax M

t_d = Time of drying (or duration of one shift of plant operation) hr

t_g = Mean grain temperature above ambient ^0C

u = A constant -

VC = Total variable cost during entire life of the plant M

VL = Value of land at the end Nth year M

v = A constant -

v_s = Specific volume of drying (heated) air at $T_h{}^0C$ m^3/kg

W = Total number of harvesting days in a harvesting season day

W_e = Weather -

W_{el} = Total number of harvesting days in an early or a late harvest period in a harvesting season day

W_r	=	Number of shifts (a shift of t_d hours) of plant operation per day	-
X	=	Depth of grain in the drying bin	m
x	=	Mean percentage of total harvesting days during peak harvest	decimal
x_2	=	Sales tax rate	decimal
x_3	=	Property tax rate	decimal
x_4	=	Insurance rate	decimal
x_5	=	Shelter cost rate	decimal
x_6	=	Height increment factor for grain elevator (>1)	-
Y	=	Year to be predicted	yr
y	=	A constant for a particular grain	-
Z	=	Storage capacity for dry grain	m^3
z	=	Mean percentage of total area to be harvested during peak harvest	decimal
ρ	=	Density of grain dry matter	kg/m^3
ρ_w	=	Density of wet grain at harvest	kg/m^3

1. INTRODUCTION

1.1 The Present Status of Grain Drying in the Developing World

Weather plays a significant role in agricultural production and processing in the developing world. Like other agricultural operations, grain drying in this region depends largely on nature's whim.

The art and science of post-harvest grain processing has made remarkable advances. Many types and sizes of grain drying facilities are available today. Despite these advances in drying technology, investment in artificial dryers in developing regions is still minimal. Wet grain handling and economic losses due to lack of use of drying facilities continue to be a problem.

Grain production in the developing world is characterized by small labor intensive farm operations, erratic weather conditions at harvest, poor farm transport and high grain moisture content. On-farm mechanical drying is rare. Sundrying is still highly preferred. Owing to small farm size and low volume of production, farmers are unable to afford expensive post-harvest equipment. They are hesitant to avail themselves of capital loans for fear of risking the only source of their income--the land that they till. This is one of the most important reasons why farmers of developing countries are still using traditional methods of grain drying and suffer significant amounts of grain loss. High fuel cost, lack of technical knowledge on drying, unawareness of existence of dryers, existence of a market for wet grain and presence of private millers to buy wet grain all make the adoption of individual dryers even more difficult.

Farmers' associations and government or other processing complexes are the major agencies shouldering the tasks of mechanical drying. Their processing plants also face a similar major problem--lack of drying capacity during peak harvest and under-utilization of dryers during good weather conditions. For example, in Indonesia, BULOG (Padua et al., 1984, p.61) reports the KUD's (a co-operative organization) lack of drying capacity in rainy periods. The KUD's drying capacities are too small to accomodate the enormous volumes of grain during rainy periods and become idle during fair weather conditions. In Malaysia, paddy harvest in the wet season has very high moisture content ranging from 25% to 35% (Yon and Nour, 1984, p.66). Wet grain and lack of drying capacities at the farm level have led to the paddy industry losing large quantities of wet season harvest. Without adequate on farm drying facilities, wet grain is sold immediately after harvest. As a result, paddy primary processing facilities at government and private milling complexes become grossly overloaded.

In the Philippines solar drying is impractical in the rainy seasons and often results in high grain loss. On-farm mechanical grain dryers have also proven financially non-viable. The best prospect for expanding mechanical drying appears to be in providing large units at rice mills (Vega, 1984, p.106). Paddy harvesting (approximately 50 % of the total production) occurs during the rainy season in Bangladesh. The public sector is obliged to purchase enormous quantities of wet grain in order to cope with the deliveries by the farmers. Bangladesh has installed batch dryers at five places attached to government procurement centers where drying problems are serious. Since those dryers were not designed on the basis of climatic conditions, they seem to have failed to satisfy the purpose of establishing the facilities.

NFA (National Food Authority of the Philippines), BULOG and other government agencies handled the wet paddy problem by using large capacity dryers with 15 to 20 ton capacities per hour. These dryers are manufactured locally. However, even with such facilities, they sometimes could not meet the drying requirements, especially during wet season harvest (FAO/UNDP, 1984, p.5). The same picture persists in other developing countries. Centralized grain processing plants in the developing world are not working properly. These plants are designed without adequately considering some important factors such as the erratic nature of weather, stochastic nature of grain production and harvest, popularity and economics of sundrying, existence of a wet grain market, local transportation problems etc. Therefore, it is extremely important to design or redesign centralized grain drying plants based on local socio-economic and weather conditions.

1.2 The Present Status of Paddy Drying and the Weather Pattern in Los Banos, Philippines

Like other regions of the Philippines, Los Banos, Laguna province of the Philippines is an important rice producing area. It is located 65 kilometers southeast of Manila at 14^0 10'N, 121^0 15'E, and 38 meters above sea level. Having almost flat land at the base of Mount Makiling in the west, Laguna de Bay is situated in the northeast of Los Banos. The average rice yield per hectare in 1978 was approximately 1.75 tons. Substantial quantities of paddy are lost annually in this area due to inadequate post-harvest facilities and handling practices. The heaviest losses are during the wet harvest seasons (May to November) and are attributable largely to inadequate drying facilities especially at the farm level. About 95% of the grain is solar dried on mats, concrete floors and road surfaces. The drying process depends largely on the random nature of weather. The weather pattern in Los Banos, Philippines from 1959 to 1983 is shown in Table 1. It shows that during the wet harvesting season the number of rainy days is very significant and the relative humidity is relatively high. During wet harvest, farmers have experinced problems of natural sun drying. Since solar drying is virtually non existent during the wet season and on-farm mechanical grain dryers have proven financially nonviable, there is a need to design a central paddy drying plant in this region.

1.3 Process of Grain Drying

The purpose of grain drying is to decrease the level of moisture content of the grain at which insect, mold, and enzymic actions are at a minimum. Grain is hygroscopic in nature and has the ability to absorb moisture when the equilibrium condition is not reached. If the vapor pressure of the moisture within the grain is higher than that of the moisture in the atmosphere, the grain will lose its moisture to the surrounding air. The grain absorbs moisture if the opposite is true.

Table 1 Climatic Averages, Los Banos, Philippines from 1959 to 1983

Month	Rainfall (mm)	Number of rainy* days (day)	Mean daily temp. (^0C)	Relative humidity (%)	Solar radiation (cal/cm2 /day)	Wind speed (km/hr)
January	40.4	9	24.9	82.9	339.6	3.9
February	17.4	5	25.4	80.1	415.5	4.3
March	27.4	5	26.6	77.4	488.5	4.6
April	32.9	5	28.3	75.8	542.7	4.7
May	173.5	11	28.9	78.6	495.2	4.0
June	240.3	17	28.3	82.0	437.9	3.2
July	279.7	20	27.6	83.8	405.5	3.2
August	255.7	19	27.4	83.9	390.1	3.2
September	269.6	20	27.4	85.6	384.0	2.8
October	239.1	17	27.0	85.0	371.1	3.0
November	254.9	18	26.4	85.0	325.7	3.5
December	158.6	14	25.5	85.3	298.2	3.7

* Rainy day is defined when rainfall is greater than or equal to 0.25 mm.

Both solar and mechanical drying are used in developing countries. Solar drying is done by simply spreading the grain on a cemented pavement or on a mat under the sun. The drying process is affected by solar radiation, humidity and other weather elements. Artificial drying is achieved by using mechanical dryers. The drying rate for a particular grain depends on a) temperature of the drying air, b) relative humidity of the drying air, c) moisture content of the grain, d) amount and velocity of air through the grain mass and e) the depth of grain in the drying bin. A flow of heated air is directed into the grain at a specified temperature and relative humidity level. The moisture content of the grain is then reduced to a certain level after which it remains stable giving no change in temperature and relative humidity. Water in the grain is vaporized by heat, water vapor is removed by air flow and the grain is dried.

There are two types of artificial dryers; the batch and the continuous type. In the batch type, there is no movement or agitation within the drying chamber. In a continuous flow design, there is a continuous agitation of grain within the drying chamber either by gravity or by mechanical means.

A centralized grain drying system usually consists of several types of equipment and facilities--grain pit, grain elevator/conveyor, temporary grain storage for wet grain, drying unit, tempering bin and storage for dry grain. Among all these components, the drying unit is relatively complex and performs several mechanical operations, using a fan, a heater or a burner, a prime mover (engine or motor) and one or more controlling devices. The grain pit receives the wet grain and an elevator/conveyor delivers the grain either to the temporary storage for wet grain or to the drying unit or to the final storage for dry grain whichever is appropriate. The drying unit performs the main function of drying. The drying rate depends on several important factors (as mentioned before). A controlling device helps to regulate some or all of the factors of drying. The dried grain or partially dried grain is removed to the storage facilities where tempering and dryeration might take place simultaneously. The partially dried grain is dried again either by the same dryer or by the sun depending on weather conditions, economics of operation, labor availability and management practices. The dry grain is then sold to the market in due time.

1.4 Need for Appropriate Model

The effect of weather on agricultural production and processing is significant. Weather risk consideration is necessary in evaluating various agricultural economic decisions. Investment in drying is one of the most difficult decision problems in grain processing.

Many developing countries are located in humid tropical regions where rice is important. More than two-thirds of the world population depends on rice for food, yet one-third of the rice crop harvested is wasted because of inadequate drying and storing (Moss, 1965). The traditional method of sundrying in developing countries depends on weather's whim. Therefore, the introduction of artificial drying facilities in these areas seems to be an efficient way to minimize grain losses. In addition to reducing weather caused grain waste, artificial drying can increase production by (Chancellor, 1967, p.1);

1. Reducing the tendency for grain to shatter from the plant while standing in the field or while being harvested.
2. Decreasing the probability of field insect-pest attack, rodent and bird attack.
3. Reducing the possibilities of field losses due to typhoon, flood etc.
4. Extending the harvest season, thereby reducing the peak labor demand.
5. Increasing the cropping intensity.

This measure is valid when the weather is bad and sundrying is not possible. The inflow of harvested grain both in terms of amount and moisture content is stochastic. The production of grain also varies randomly from year to year. Furthermore, the drying rate is also affected by the random variation of weather elements such as relative humidity of air, rainfall and air temperature. The question about the economical size of drying and storing facilities becomes a very difficult one to answer. Farmers rely on solar drying when the weather is favorable. Artificial drying is used when the weather is not suitable. In good years, (i.e. the year in which adequate solar radiation is available for grain drying), drying facilities are idle. Thus, weather uncertainty makes the investment on drying facilities highly risky.

Many studies on the selection and design of grain drying or similar systems, have been reported (Carpenter and Brooker, 1972; Lytle et al., 1974; Chang et al., 1979; Wimberly and Sistler, 1982;). Almost none of the studies adequately deal with the design of grain drying plants under the situations characterized by the stochastic nature of weather, the random supply of grain both in terms of amount and moisture content and the year to year variation of grain production. Due to failure of considering these variables adequately, many existing centralized grain drying plants are found to be uneconomical. No general and complete model or report was found that can be effectively used for designing or evaluating a grain drying plant under real world situations. A quantitive management model which can integrate adequately all these variables and help decision-makers to locate the optimal course of action would be very welcome. Therefore, an attempt has been made to develop a general simulation model that can be effectively used for designing and evaluating a grain drying plant equally applicable to all grain growing areas of the developing world.

1.5 Objectives

The objectives of this study are;

1. To develop a simulation model which represents the complex interaction of the dynamic and stochastic nature of centralized grain drying and storage systems.
2. To apply the model to an example for selecting the optimum capacities of drying and storage facilities.
3. To evaluate the system with possible alternatives of drying parameters, facility capacity and management alternatives.

4. To make the model general and operational, so that potential users can handle the model and analyze the results.

2. LITERATURE REVIEW

Substantial research has been conducted on various aspects of post-harvest grain processing systems. Literature search has found no specific reports that consider the effects of weather uncertainty, drying strategies and management alternatives on grain drying systems. Price (1964) developed a regression model that evaluated and compared in-plant economics of scale for selected kinds of rice drying and storage facilities. The model included total drying and storage costs as dependent variables, with drying and storage output plus excess capacity as independent variables. Long run total drying and storage cost functions were estimated by least square multiple regression equations. The objectives of his study were; a) to determine the most efficient (least cost) output by size for rice drying and storage facilities, b) to determine the most efficient drying system as size and output level change, c) to determine the influence of co-operative ownership on commercial drying and storage facilities and d) to determine the influence of the drying and storage system on rice quality. These objectives were accomplished through a cost study of drying and storage operations of a cross-section of farms in Louisiana and Texas. Random samples were drawn for the study and operating costs were obtained from sample firms for three consecutive years (1959-61). The seasonal pattern of rice receipts was considered as an average of the five year period, 1958-62. This model ignored the effects of weather and the random supply of grain and did not represent grain drying systems in developing countries.

A simulation model was developed by Carpenter and Brooker (1972) to analyze costs associated with harvesting, drying and storing systems for shelled corn. The model provided a means of evaluating the effect of the size and type of equipment used in the system. The model was capable of evaluating the time of harvest, date of maturity, level of field losses, relative risks etc. This model seemed to be developed for on-farm corn processing and did not consider the effect of weather uncertainty, therefore, it was not suitable for a grain processing system where weather is the main concern.

An on-farm grain drying and storage system simulation model was developed by Lytle et al. (1974) to compare and analyze performance characteristics of various grain drying and storage systems. The purpose of their research was to develop a simulation model that generates cost and operational performance information for grain drying and storage systems. Inputs to the model and examples of types of output from the model were presented. Cost information was used to compare the operational efficiency of alternative systems and to determine the optimal number of bushels that a particular system should dry and store. Optimum operational efficiency was achieved at minimum average per bushel cost subject to the system being large enough to dry and store at a given harvest rate. The model was deterministic excluded weather uncertainty, drying strategies and management alternatives.

Chen (1974) concluded that sundrying of rice in Taiwan was still economic and satisfactory. For preserving the grain from spoiling due to bad weather, artificial drying was necessary. The research result also indicated that a continuous rice drying system was better than a batch type system so that rice of different qualities or rice owned by different farmers could be separated after drying. Chen made an interesting recommendation that, compared to natural solar drying, a thorough drying to 13% moisture content was not economic for artificial dryers of any kind. Heated air drying of grain to 18% moisture content for short period safe storing was recommended. Chen suggested that grain be dried further by the traditional way (sundrying) to the desired moisture content, if drying cost was the sole consideration.

Young and Dickens (1975) studied batch and cross-flow drying systems to evaluate the cost for drying grain. A method for evaluating the drying costs and the effects that various drying parameters have on these costs were discussed. The model used in the study considered some of the weather elements. This study was helpful to the development of the model, representing centralized grain drying systems design and management for developing countries.

An important research work on emergency rice drying in the rainy seasons was conducted by Chen (1975). His study indicated that a continuous flow multipass drying plant integrated with a floating layer could be the best combination for future rice dryers for farmers' associations. He pointed out that emergency rice drying differs from normal rice drying in that the former concerns itself with how fast a mass of wet grain is treated for safe storage for a period of time until unfavorable weather is passed. Chen's study was very useful, but did not offer any model suitable to analyze grain drying under unfavorable weather conditions.

Loewer et al. (1976) utilized a previously developed simulation model, BNDZN, to generate comparative purchase and annual cost for layer, batch-in-bin, and portable drying facilities. The important designs incorporated in the model were capacity, number of bins, harvest rate, and the degree of mechanization. No differences in grain quality or labor requirement among the different drying techniques were considered. Also, it did not include stochastic weather elements such as sunshine, rainfall, temperature and relative humidity of air.

Turner and Baker (1976) investigated and analyzed total costs involved in drying and handling of corn and grain sorghum in Nebraska grain elevators. It analyzed costs for complete grain drying-handling-storage systems. It also showed the relationship between plant size, cost of drying and associated handling, but ignored the stochastic effects of weather elements.

Chang et al. (1979) developed a mathematical model for dryer selection, based on empirical study. The model was primarily designed for selecting an on-farm drying facility at optimum cost. In the process of modeling, more than 100 dryer specifications were examined. Thermal efficiencies and optimum dryer capacities were also analyzed for five different drying systems. The model was developed by taking four steps a) collecting more than 100 different dryer specifications obtained from 22 dryer and handling equipment manufacturers in the United States, b) mathematical modeling of the dependent variables as the functions of the independent variables, c) development of dependent cost functions, and d) optimization of drying system requirements. Drying costs were divided into four categories--

operating costs, fixed costs, timeliness costs and miscellaneous costs. Since the model was developed only for the purpose of selecting a dryer, therefore, it is not capable of analyzing the post-harvest grain processing systems as a whole. Furthermore, the model did not consider random behavior of weather, drying strategies and management alternatives etc. This model included only the deterministic nature of inputs.

Habito and Duff (1979) developed a simulation model for a rice post-production system at the farm level for developing countries. It simulated the farm post-harvest operation of a hypothetical 1.5 hectare rice farm consisting of 15 plots of varying sizes. Only two basic technology systems were modeled; a) the traditional system, employing manual harvesting, cleaning and solar drying, and b) a partial mechanized system, employing manual harvesting, threshing with the IRRI-designed axial flow thresher, and drying with a twin-bed 2 ton batch dryer. However, the model incorporated uncertainties affecting different processes in the system, particularly weather effects and availability of labor. The main purpose of the model was to investigate the nature of trade-offs between increased costs and the gained advantages of mechanizing rice post-harvest tasks. The model seemed to be unsuitable to design a grain drying system. Although, it considered weather uncertainties and the stochastic nature of labor input, it was rather specific, inflexible and difficult to evaluate the effects of various relevant factors affecting the drying system.

Costs of owning and operating on-farm drying and storage facilities for rice was studied by Woody and Morrison (1979) for Arkansas farms. Their study was to provide economic information on costs of storing and drying rice on the farm, with special emphasis on energy costs and requirements. The specific objectives were to a) estimate the quality and cost of energy necessary to reduce the moisture content of a bushel of rough rice, b) evaluate the effects of weather conditions on energy requirement, c) develop estimates of necessary capital investments and d) simulate costs of owning and operating on-farm drying facilities. These objectives were accomplished by a case study analysis of two types of on-farm drying-storage systems. One facility was a 43,200 bushel incline auger facility, the other was a 60,000 bushel capacity elevator facility. Weather effects were also studied in an attempt to estimate the effects of temperature, precipitation and humidity on the drying process and on the quality of energy used. However, the study was farm and system specific and did not focus on the design of the facilities.

In 1982, a feasibility study for a modern post-harvest facility and a marketing facility for rice in the Cagayan valley of the Northern Philippines was undertaken by the Asian Development Bank (ADB). The proposed project had five components--three concerned with rice and two with fruits and vegetables. A component of the project (out of six) augments post-harvest facilities in the locality by providing threshing, drying, storage and transport facilities capable of handling 100,000 tons of paddy. The objectives of this project were to assure supply of quality paddy to the integrated milling complex and of bridging the anticipated gap of required infrastructure in the wake of the commissioning of new irrigation facilities; help salvage from the present post-harvest losses about 36,000 tons of rice and 17,000 tons of fruits and vegetables; make a net contribution to the country's energy balance by producing energy out of rice hulls; and convert rice barn as a more nutritious feed. This feasibility study did not use a model for designing a drying facility suitable for developing nations.

A computer model was developed by Wimberly and Sistler (1982) for selection of commercial scale rice drying components. The model was designed to select the major components of a continuous flow, four pass, commercial-scale rice drying facility and to analyze the cost of the facility over its estimated useful life. The program also analyzed facilities with different design layouts and grain bin diameters and ranked the facilities by net present cost. However, the model did not include the random nature of input variables. Variables such as grain receiving rate, initial moisture content and final moisture content were assumed to be deterministic. Furthermore, it did not consider the effects of weather variables.

A feasibility study of a thresher-drier-mill operation at the farmers' association level was conducted by Manilay and Lorenzana (1984). About thirty six project alternatives were considered in the feasibility study using several basic case assumptions such as, a) the volume of paddy for milling was 506 tons per year and was constant for 5 years; b) two units of axial flow threshers operated for a duration of 120 days per year, 8 hours per day at 100% capacity utilization; c) one unit of rice hull-feed batch dryer operated for 60 days during the wet seasons, at 10 hours a day, 100% capacity utilization; d) threshing, drying and milling fee computed as the cost per unit plus a 30% mark-up; and e) one unit of a Thai village "Engleberg" mill operated for 126.5 and 109 days during the dry and wet seasons, respectively, at 8 hours per day, 5 days a week. The project feasibility was analyzed using an Internal Rate of Return method. The main objective of the study was to present alternative cases and their corresponding rate of return to investment. Only in certain cases, reducing drying operations from 60 to 30 days per year simulated the possiblity that some farmers will still practice sundrying whenever the sun is available during the wet season. However, this study did not consider the stochastic nature of weather variables, the probabilistic demand of grain drying during sunny and non-sunny days and management alternatives. Furthermore, the study did not focus on the capacity design of the plant as it was rather specific and deterministic in nature. The study also did not present a model for designing and evaluating a drying facility suitable for developing areas of the world.

In short, the literature search has revealed that numerous research has been performed in developing grain drying theories, methods, cost-benefit analyses and feasibility studies of grain processing complexes. Only a few reports have pointed out that there is a significant effect of weather on design and economic performance of grain drying systems in the developing countries. However, no specific and complete report has yet been found that adequately considers the effects of weather on grain drying system design and management in the developing world.

3. METHODOLOGY

3.1 An Approach to Model Development

A centralized grain drying system can be represented as a process of interrelated operations (Figure 1). Weather elements, such as solar radiation, air temperature, air humidity, rainfall and wind have highly significant effects on this process. The stochastic nature of these elements makes the system difficult to analyze. The traditional approach of breaking down the total system into sub-systems for separate analysis proves to be inadequate. Evaluation of the overall system response to any activity of the entire drying system is very difficult to obtain without a model. For example, decision to change the capacity of a grain storage facility cannot be evaluated on the basis of the effects on that particular facility alone. Related economics, weather variables, management strategies and physical impacts on all other components of the entire drying process have to be considered in order to arrive at the overall system response. Therefore, the system approach has been followed in modeling the complex grain drying system.

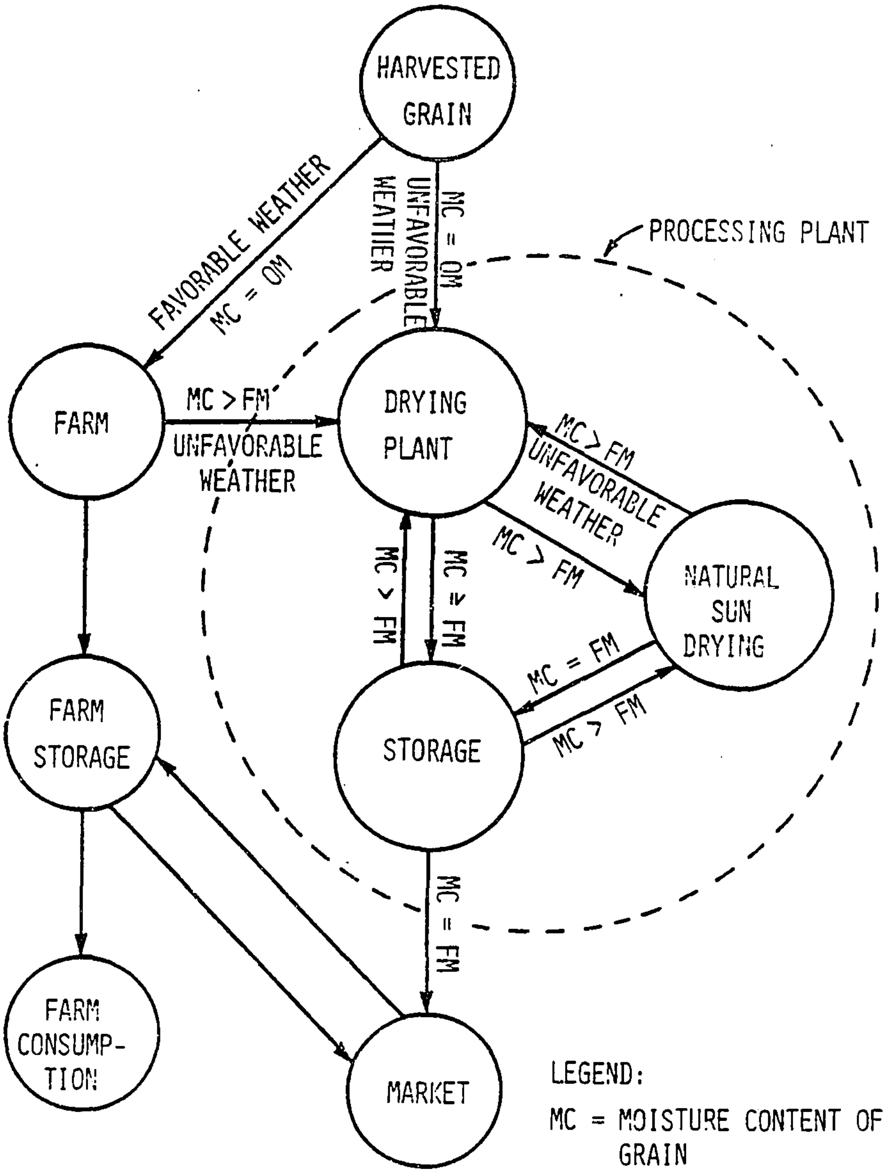

FIGURE 1 GRAINFLOW PATTERN AND ITS MOISTURE CONTENT IN AND OUTSIDE OF THE PROCESSING PLANT

LEGEND:

MC = MOISTURE CONTENT OF GRAIN
OM = MOISTURE CONTENT OF GRAIN AT HARVEST
FM = FINAL MOISTURE CONTENT OF GRAIN

Since a model is a simplified representation of a real situation, it may not be valid (perfectly correct) under all conditions. It is usually too costly and time consuming to construct a model for all conditions. Thus, the following assumptions have been considered to simplify this model.

1. Farmers sell their grain to the processing plant when the weather is not favorable for on-farm sundrying.
2. All grain is treated as a loss if it is kept beyond the safe storage period.
3. The service area of the processing plant is reasonably small so that the local transportation cost is insignificant when compared to the value of grain losses.
4. The reliability of the drying plant is satisfactory. In other words, there is no major plant failure or breakdown during operation.

The management strategies considered during development of the model are as follows:

1. Grain may be partially dried by the plant if the grain can be redried later by natural sundrying or by the plant or both.

2. All stored grain is sold to the market when a better market price can be expected within a year.
3. Dry grain that cannot be stored due to limited storage capacity is sold at a lower price to the market immediately.

Since the socio-economic atmosphere and weather conditions of the Philippines fairly represents the developing world, necessary data from the Philippines have been utilized for development and verification of the model. Model information flow within the plant management is shown in Figure 2.

3.2 The General Structure of the Model

The model (WEGDM) consists of three major components, namely, Simulation Program for Weather Variables (SPWV); Simulation Program for Grainflow, Drying and Management (SPGDM); and Simulation Program for Financial Analysis (SPFA). These are discussed in detail in the following sections. A flow diagram of the complete model is shown in Figure 3 and the computer program in FORTRAN 77 language of the entire model is listed in Appendix L. The model has been developed with a view to satisfy the objectives of the study only. Three criteria that are most frequently considered to determine the profitability of an investment project are the

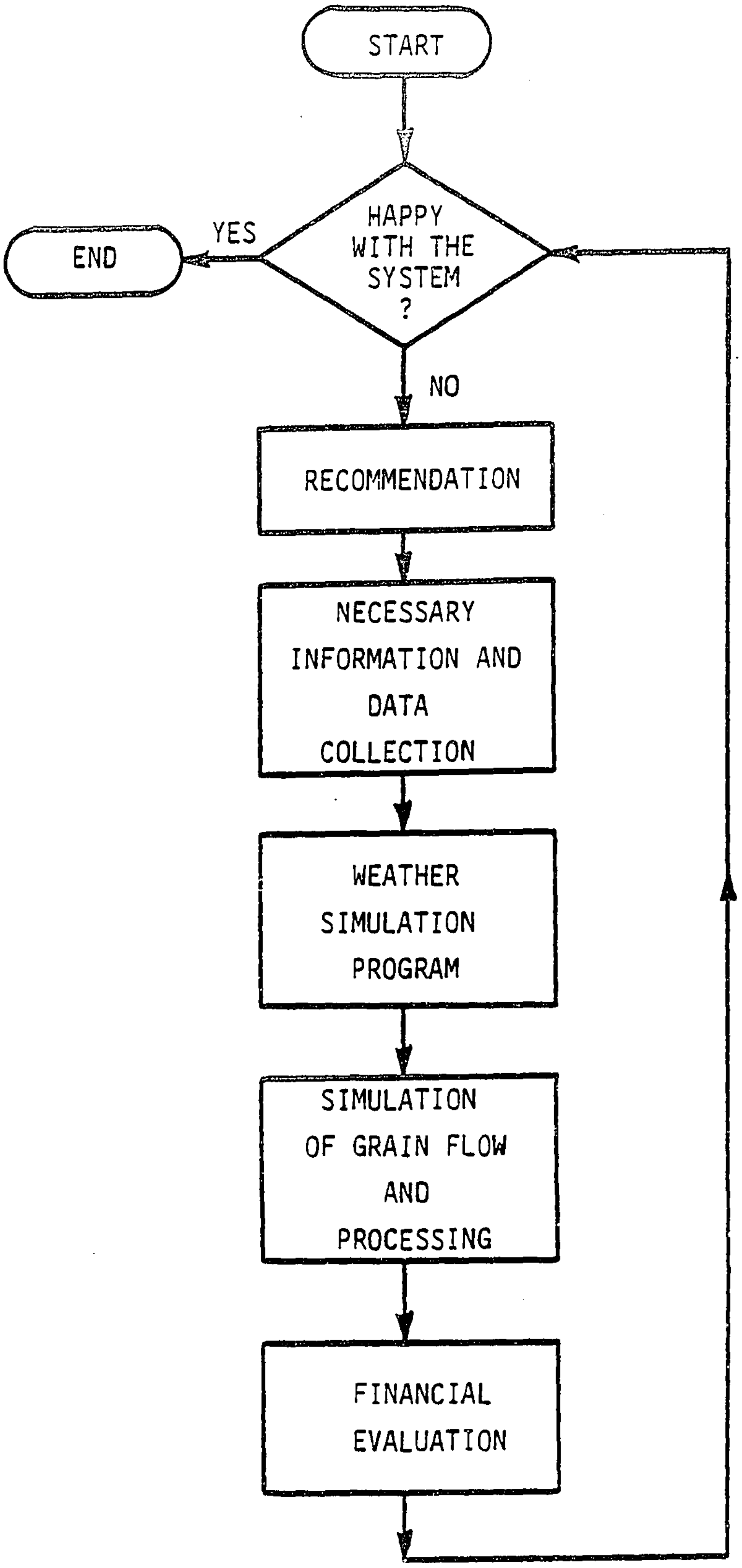

Figure 2 The Interactive Relationship Between Major Model Components and Project Management

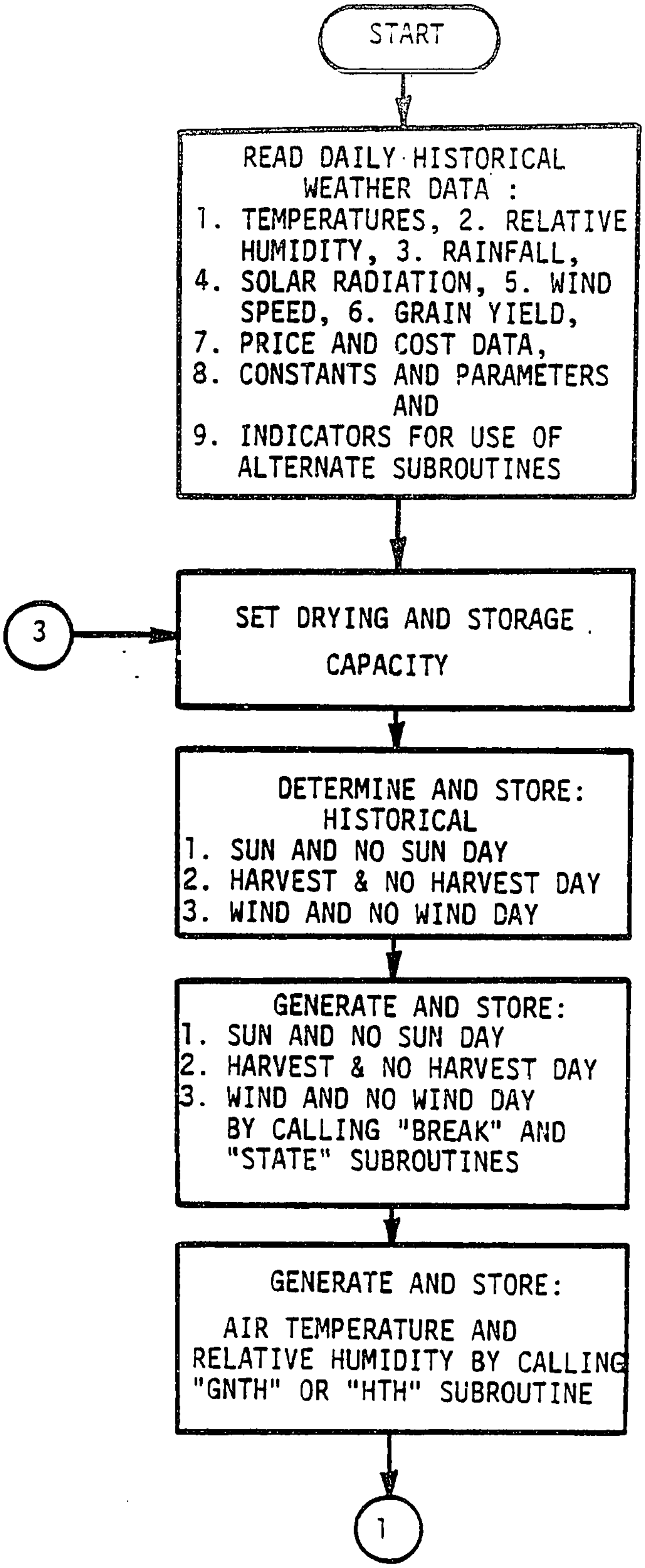

Figure 3 The Flow Diagram of a Centralized Grain Drying System Model (cont.)

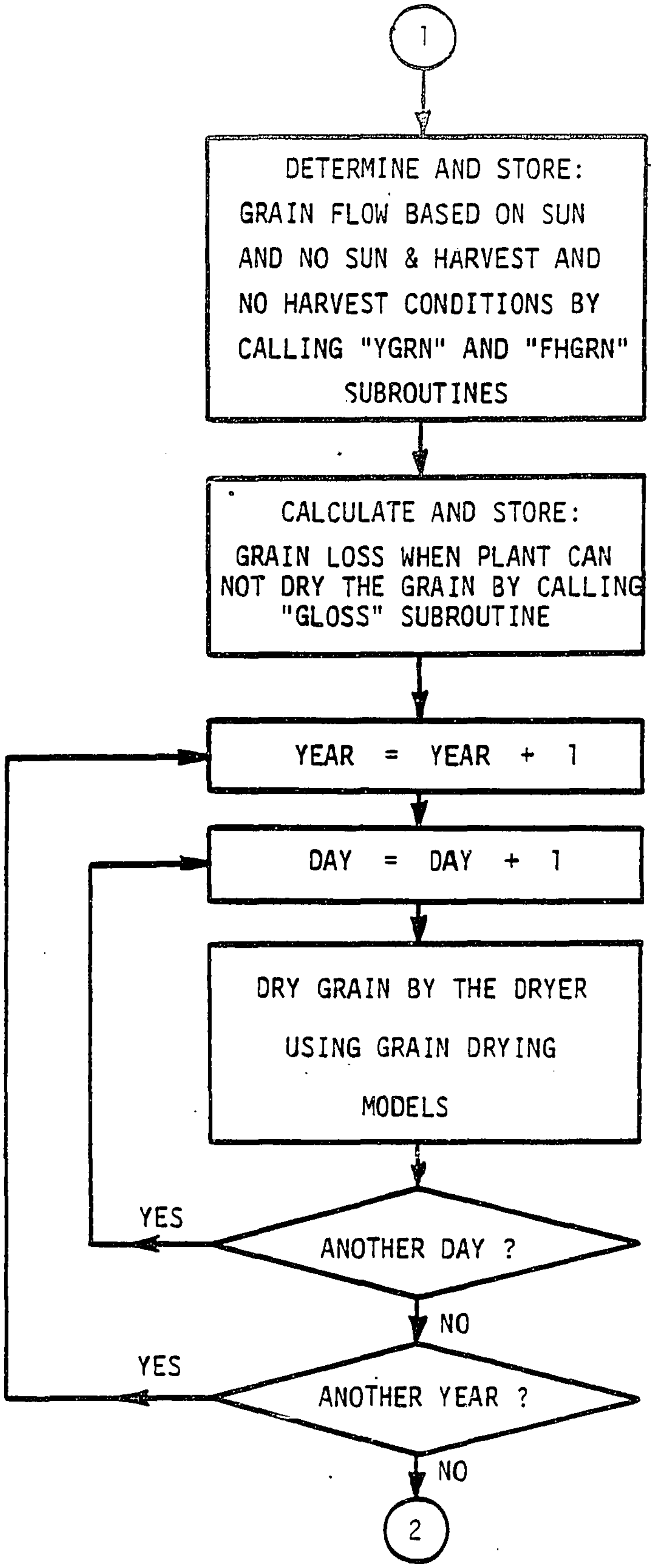

Figure 3 The Flow Diagram of a Centralized Grain Drying System Model (cont.)

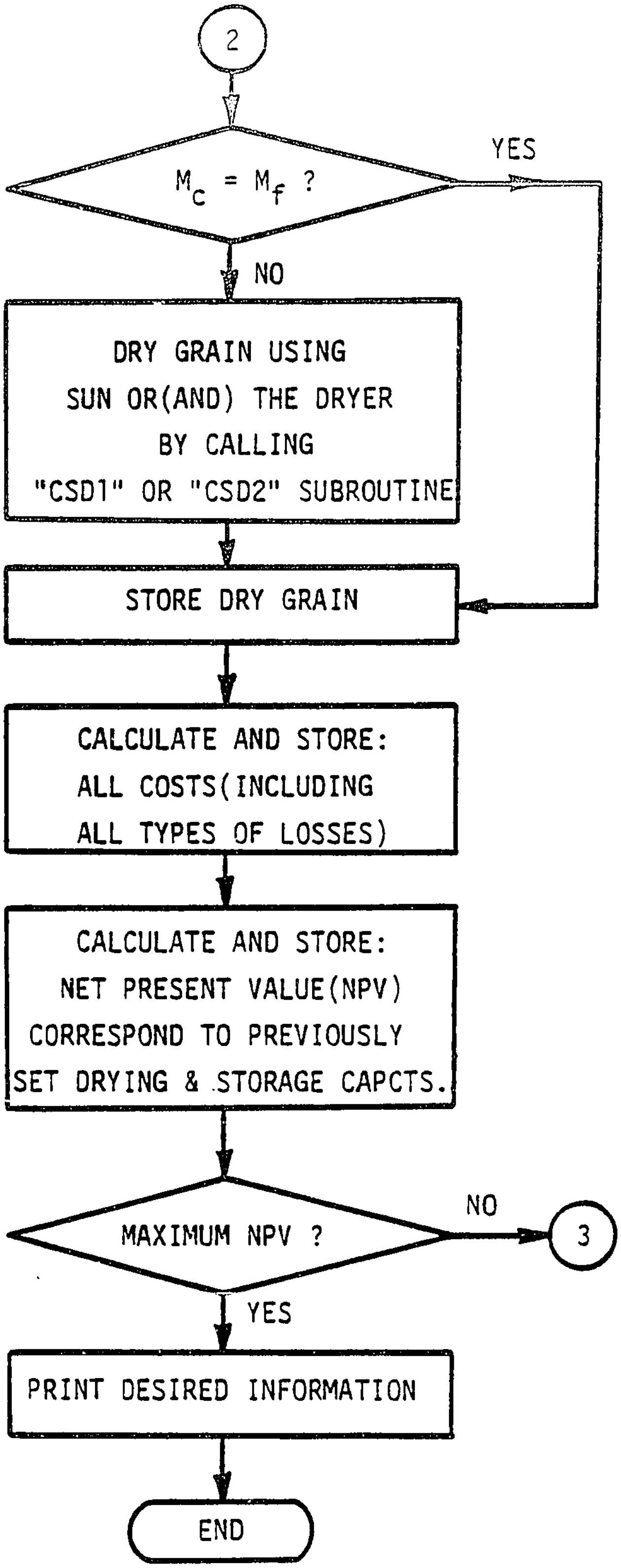

Figure 3 The Flow Diagram of a Centralized Grain Drying System Model

payback period, the internal rate of return and the net present value (discounted present value). Among these commonly used investment decision-making criteria, the Net Present Value (NPV) of cash flow seems to be very appropriate to the system to be analyzed. The payback period criterion is a crude rule of thumb and does not have any decision power in evaluating a single project where there is no scope of project comparison. On the other hand, the marginal efficiency of investment or internal rate of return is computationally more difficult when compared to other investment decision-making methods. Thus, the Net Present Value (NPV) of cash flow is considered as the design and investment criterion of the model. It is used as the basis to determine the optimum size of the plant and to assess the profitability of the investment. The key part of the overall criterion is;

$$\text{Maximize NPV} = \sum_{i=1}^{N} \frac{NCF(i)}{(1+r)^{i}} + \frac{PSV}{(1+r)^{N}} + \frac{VL}{(1+r)^{N}} - INF - LAN$$

with respect to D_r, Z and W_e

where,

D_r = Drying capacity of the plant, m^3/t_d hr

INF = Initial investment in equipment and

facilities, M (Money unit)
LAN = Initial land value, M
N = Number of simulated year, yr
NCF(i) = Net cash flow for the year i, M
PSV = Plant salvage value at the end of Nth year, M
r = Interest rate, decimal
VL = Value of land at the end of Nth year, M (See Appendix C equation 37)
W_e = Weather
Z = Storage capacity for dry grain, m^3

The model generates weather variables; determines the amount of harvested grain, moisture content of the grain and grainflow; and calculates costs and grain losses necessary to analyze the grain processing system. The principle used in modeling the grain drying system is to dry the grain at a specified time period (input variable). Since drying depends on air flow rate, the grain is dried in the specified time by controlling air flow rate through the grain bin.

Based on prior harvest information and intuitive judgement, initial values are assigned to the drying and storage capacities for optimizing the system. For a specific weather pattern, the NPV of cash flow corresponding to the drying and storage capacities, keeping other variables fixed, is calculated. A series of NPVs are calculated for each combination of drying and storage capacity of the plant (Figure 3). A potential optimum drying and a potential optimum storage capacity of the plant may be obtained at the maximum NPV of cash flow--for a specific weather pattern. The term 'potential optimum' refers to optimum capacity of the facilities for a particular weather pattern. These values might change with the change of weather pattern but possess the potential power to be the optimum. Keeping the storage capacity to this potential optimum level, the process is repeated to get different potential optimum drying capacities for each different weather pattern. The different weather pattern may be generated using randomly selected DSEED in the random variable generation process. The variances of NPVs (NPVs are obtained at different weather patterns) corresponding to each of the potential optimum drying capacities are calculated. The optimum drying capacity of the plant could be found at the minimum variance (i.e. at minimum weather effect) of NPVs. To the obtain optimum storage capacity of the plant, storage capacity is varied, keeping the optimum drying capacity fixed along with the corresponding weather pattern. A series of NPVs are calculated. The optimum storage size could be obtained at the maximum NPV of cash flow.

3.2.1 Simulation Program for Weather Variables (SPWV)

The purpose of this program is to simulate necessary weather variables. It determines historical sun-no sun days, harvest-no harvest days and wind-no wind days, based on critical levels (A, B, C, D and E in Figure 4) of rainfall, solar radiation and wind speed. These critical levels are selected through extensive study of historical weather data, field experience and intuitive judgement. The program SPWV generates sun-no sun days for grain drying, harvest-no harvest (work-no work) days and wind-no wind days for grain harvesting, using Markov Transition Probabilities. The program itself is capable of calculating Markov Transition Probabilities and in order to do so, a vast amount of historical weather data is needed. Input weather variables used by the program are daily maximum and minimum air temperatures, daily mean air relative humidity, daily rainfall. daily solar radiation and daily wind speed. The simulation flow diagrams of the SPWV program are shown in Figure 5, Figure 6 and Figure 7.

Historical daily air temperature and relative humidity have been utilized directly in this analysis. However, the SPWV is flexible enough to generate air temperature and relative humidity using fitted probability distribution to the observed data. An optional subprogram has been

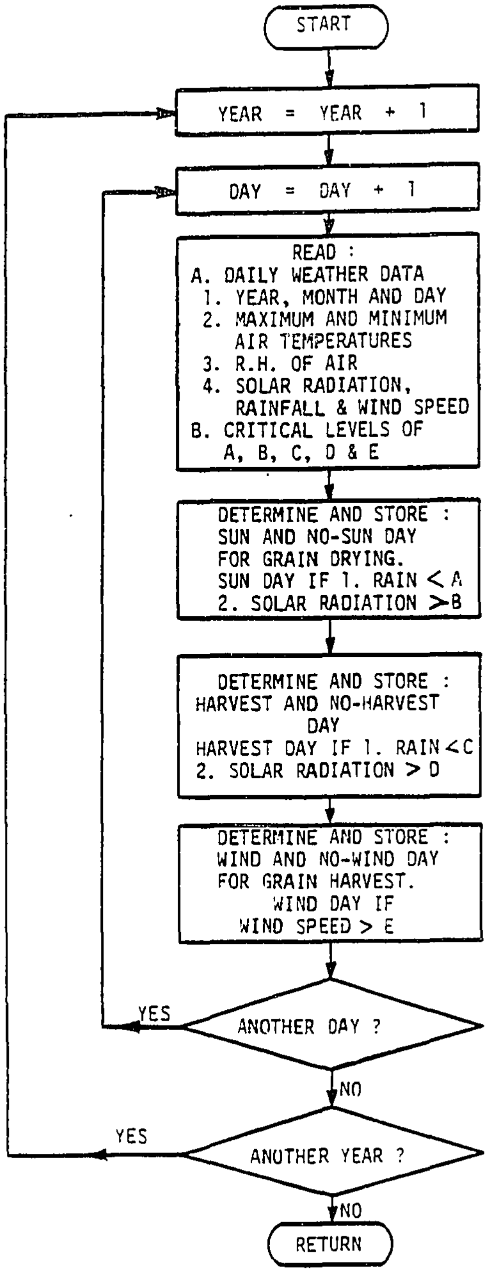

Figure 4 The Flow Diagram for Simulating Sun-No Sun Days, Harvest-No Harvest Days and Wind-No Wind Days

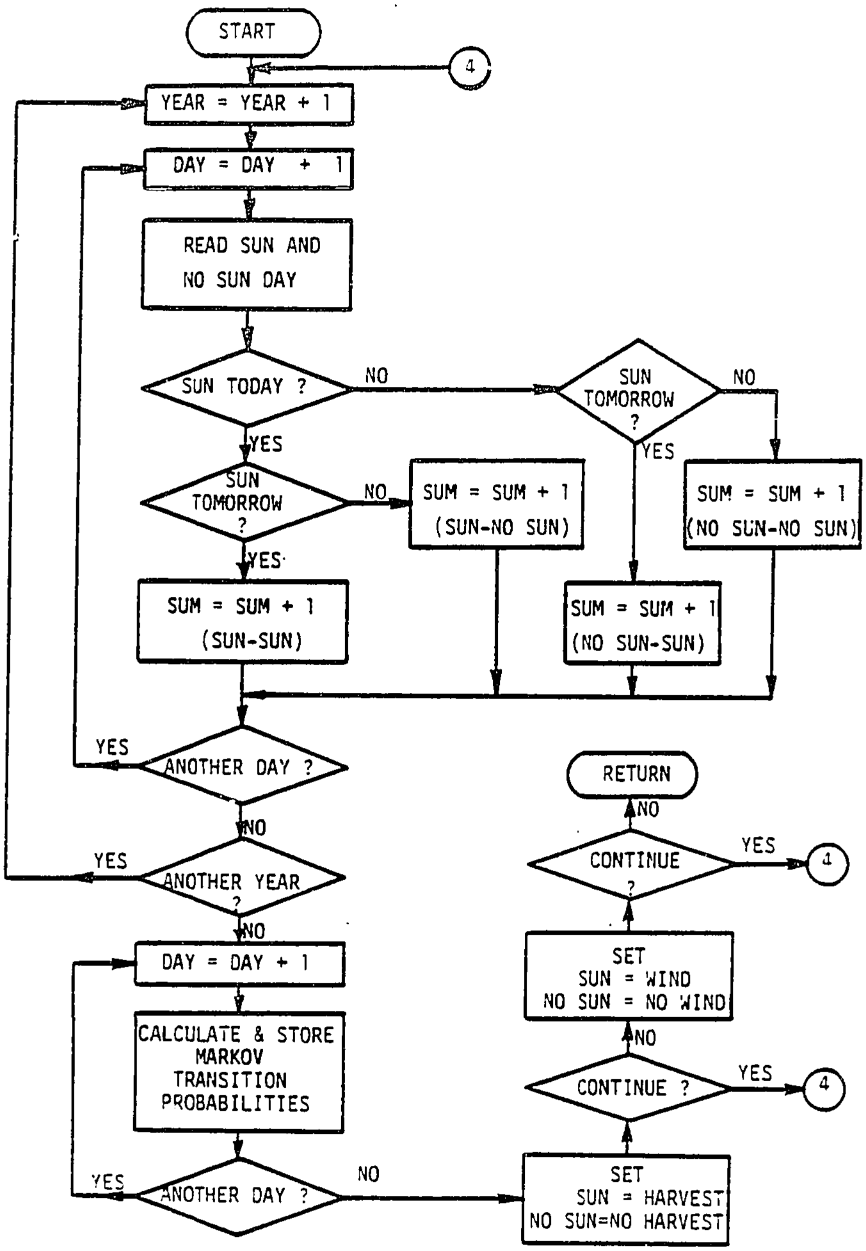

Figure 5 The Flow Diagram for Calculation of Markov Transition Probabilities of Sun-No Sun Days, Harvest-No Harvest Days and Wind-No Wind Days --the BREAK Subroutine

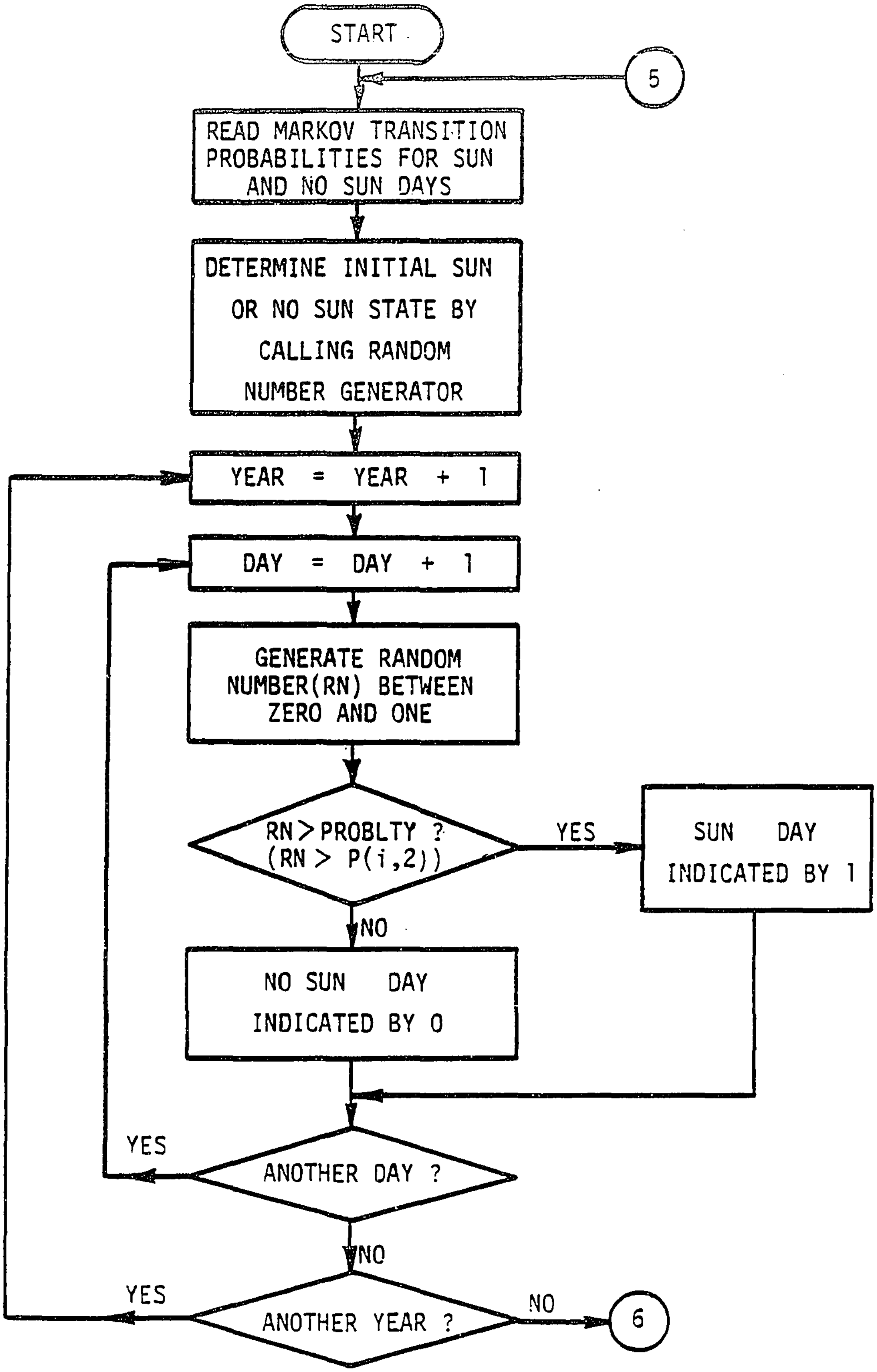

Figure 6 The Flow Diagram for Generation of Sun-No Sun Days, Harvest-No Harvest Days and Wind-No Wind Days--the STATE Subroutine (cont.)

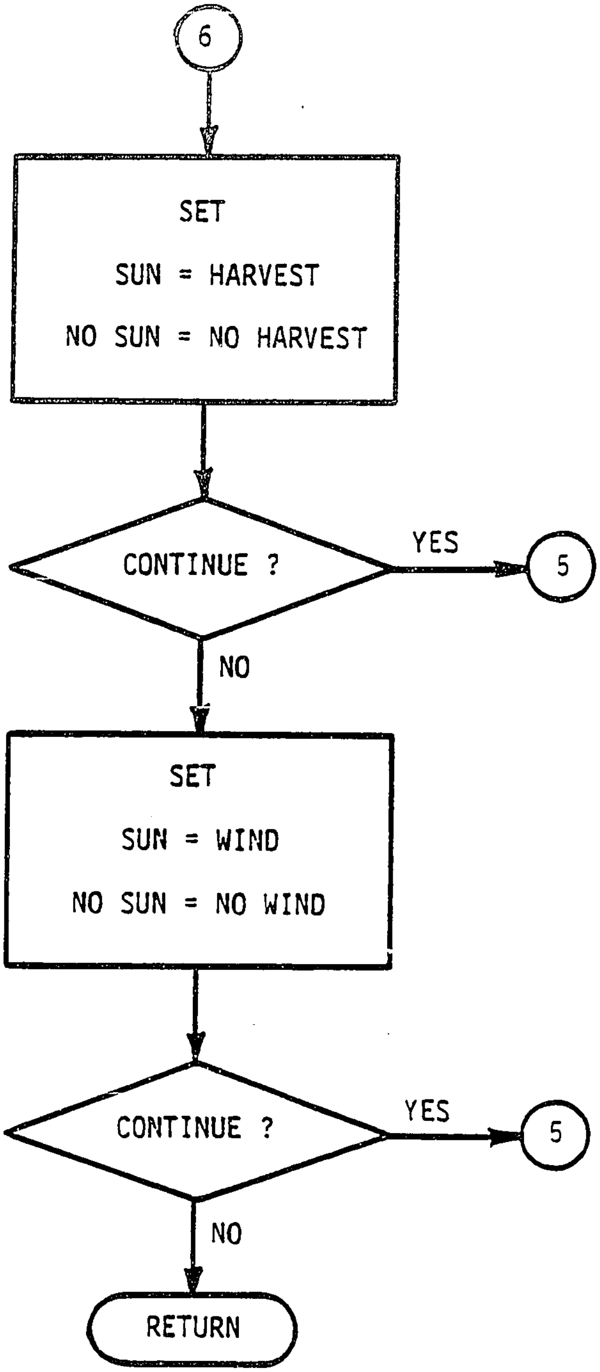

Figure 6 The Flow Diagram for Generation of Sun-No Sun Days, Harvest-No Harvest Days and Wind-No Wind Days--the STATE Subroutine

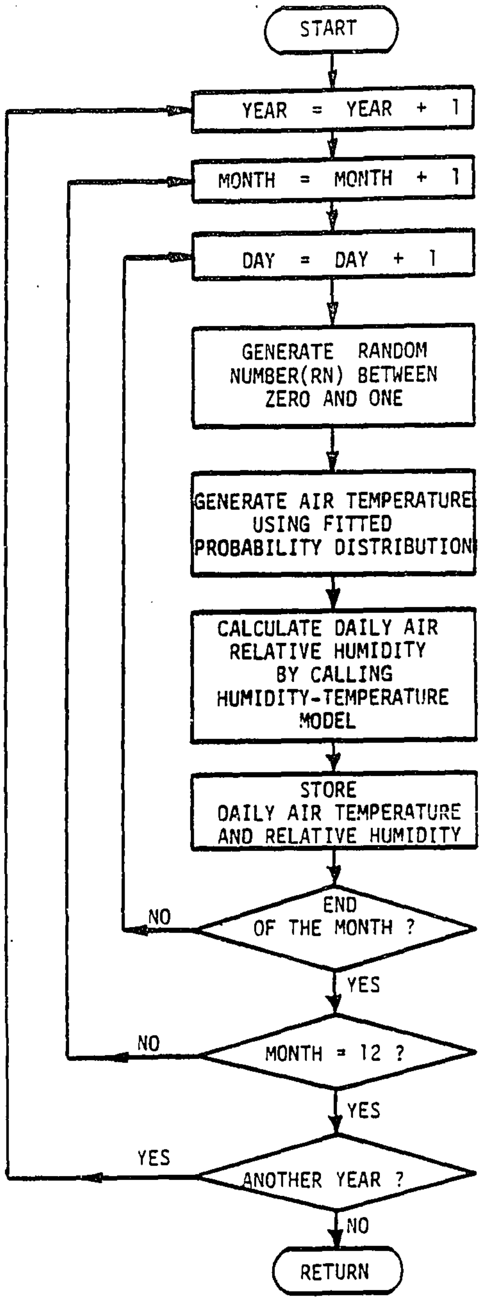

Figure 7 The Flow Diagram for Generation of Daily Air Temperature and Relatively Humidity--the GNTH Subroutine

incorporated into the SPWV program to make the model operational in a locality where discontinuous or missing historical data exists. The appropriate monthly probability distributions are fitted (Table 2 and Appendix D) to the observed air temperature data with the help of the interactive computer package--UNIFIT (Law et al., 1983). Based on the nature of histogram of observed monthly air temperatures, eight potential standard probablility distributions (Normal, Logistic, Extreme Value Type A, Extreme Value Type B, Weibull, Lognormal, Inverse Gausian and Gamma) are selected. Only these distributions are fitted to the observed data. From a cursory analysis of the eight distributions based on relative discrepancies from straight line (Probability-Probability Plot and Quantile-quantile Plot) and model test comparisons (CHI-square, Kolmogorov-Smirnov and Anderson-Darling), the best fit of the eight distributions may be selected. Using the best fitted distributions, the program (Figure 7) can simulate daily air temperature necessary for grain drying. Relative humidity of air could be generated by using the fitted regression model (Table 3) relative humidity of air and temperature. This data is needed to simulate energy cost of grain drying and to determine the safe storage life of the grain.

Table 2 The Fitted Probability Distributions to Daily Air Temperature (^{0}C) in Los Banos, Philippines from 1959-1983

Month	Fitted Distribution	Location Parameter	Scale Parameter	Shape Parameter	CHI-Square Value	Degree of Freedom
January	Logistic	24.9499	0.698483	-	38.1587	22
February	Weibull	0.0000	25.958000	23.78950	11.0524	22
March	Weibull	21.3445	5.792680	4.65088	16.7445	21
April	Weibull	0.0000	28.753500	32.64760	33.8690	22
May	Weibull	0.0000	29.408000	29.18990	38.2516	22
June	Logistic	28.3008	0.623223	-	34.1759	22
July	Weibull	22.8514	5.130380	5.29442	21.5754	21
August	Logistic	27.4519	0.596543	-	39.3625	22
September	Logistic	27.3650	0.555387	-	37.5198	22
October	Weibull	0.0000	27.417800	33.00840	23.2941	22
November	Weibull	0.0000	26.847500	29.28840	27.7439	22
December	Weibull	21.1176	4.818930	4.28437	25.1987	21

Table 3 The Fitted Regression Model to Weekly Air Relative Humidity and Temperature in Los Banos, Philippines from 1959-1983

Month	Regression Model	R^2	F	$S_{y.x}$
February to April	RH = 39.53 + 1022.300 T^{-1} (110.78)	0.8856	85.164	0.700
May to October	RH = 185.82 - 3.699 T (0.30)	0.8595	146.761	1.017
November to January	RH = 115.31 - 793.540 T^{-1} (229.93)	0.5436	11.911	0.826

RH = Relative humidity of air (%) ; T = Air temperature (^{0}C)

3.2.2 Simulation Program for Grainflow, Drying and Management (SPGDM)

The program SPGDM has been designed to simulate necessary cost information that is needed for financial evaluation of the plant by the Simulation Program for Financial Analysis (SPFA). It simulates the amount of grain flow and its movement as shown in Figure 1. The program can calculate all possible grain losses during processing and handling. The losses considered by the model are: grain loss if it is kept beyond its safe storage period, grain loss due to limited capacity of the dryer and loss due to the limited capacity of grain storage. In addition, it simulates and gathers information regarding costs such as the energy cost of grain drying, the cost of operating the fan-motor system, the cost of elevating/conveying the grain, the cost of grain drying by natural sundrying and labor costs. The models used for these cost computations are shown in Appendix A. The simulation flow diagrams used in the SPGDM program are shown in Figure 9, Figure 10, Figure 11, Figure 12 and Figure 13.

3.2.2.1 Harvesting Model

The harvesting model simulates the daily amount of grain harvested in a harvesting day (working day), using mean land productivity and the daily total area harvested within the service area of the plant. The program SPWV generates harvest-no harvest days based on critical levels of rainfall and solar radiation, using Markov Transition Probabilities. However, a day is also considered suitable for harvest if the following day is windy. Due to lack of historical data or an appropriate model, the daily area harvested is determined from a hypothetical model as shown in Figure 8. The model assumes that during peak harvest the area harvested per day is constant because of the limitation of resources, such as labor. The mean percentage of area harvested and the mean percentage of harvesting days in each harvesting season in a year may be gathered from interviews with the farmers. The program SPGDM is quite capable of calculating the amount of grain harvested within the service area of the plant in a harvesting day. The detail of the model is discussed in Appendix B.

3.2.2.2 Moisture Content Model

A moisture content model is designed to simulate the moisture content of the grain at harvest. The behavior of moisture content of the grain depends largely on plant physiology, soil parameters, weather, the planting and the harvesting date and is very difficult to estimate correctly.

LEGEND:

A_h = Total area to be harvested during peak harvest, ha
D_a = Total number of harvesting days in a period of peak harvest, day
T_A = Total crop area within the service area of the plant, ha
W = Total number of harvesting days in a harvesting season, day

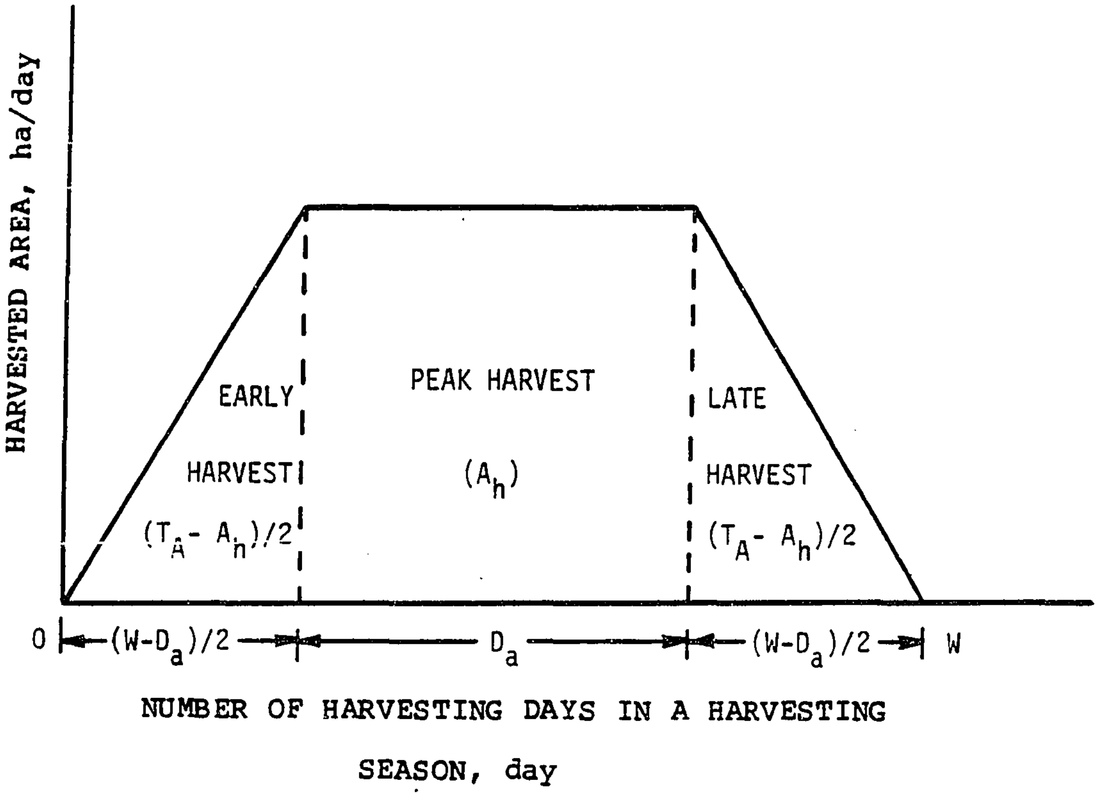

Figure 8 A Hypothetical Pattern of Daily Grain Harvest in a Harvesting Season

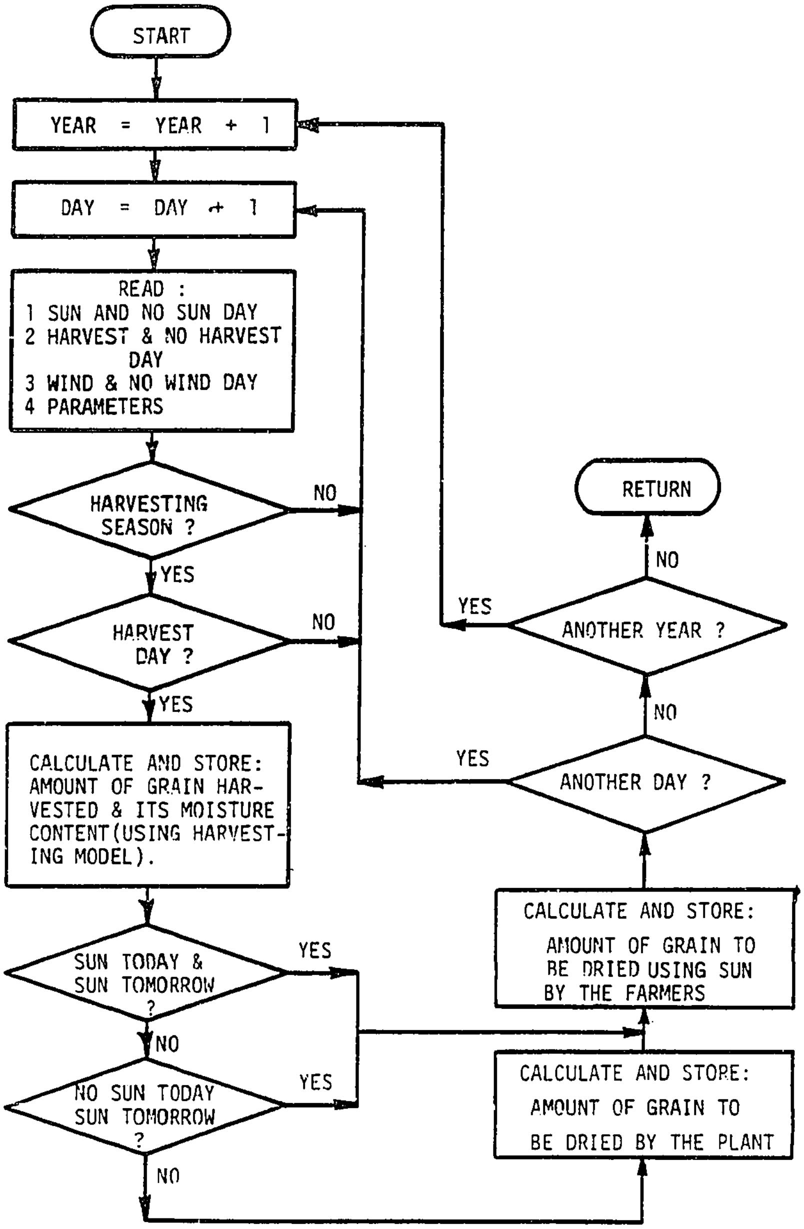

Figure 9 The Flow Diagram for Grainflow of the Harvested Grain--the YGRN Subroutine

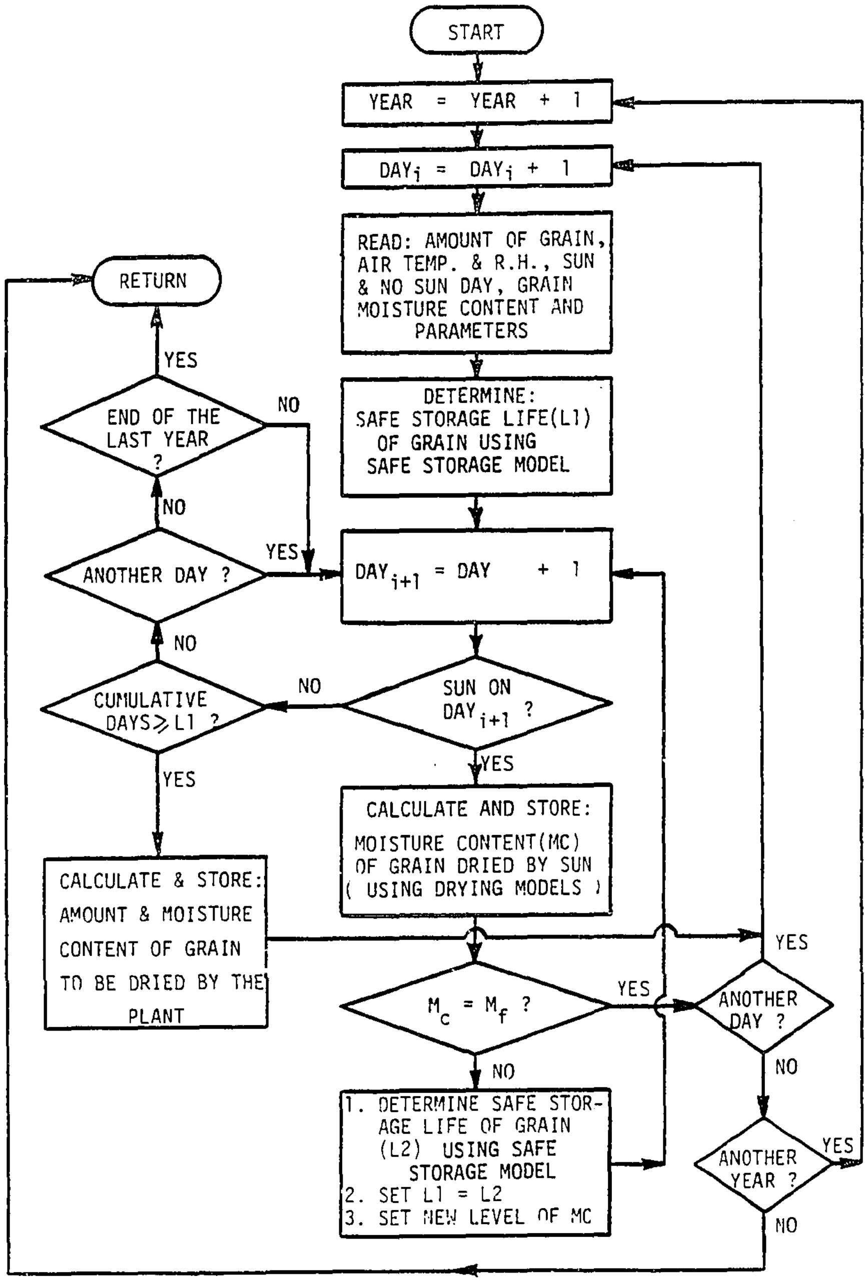

Figure 10 The Flow Diagram for Movement of Partially Dried Grain from Farmer's House--the FHGRN Subroutine

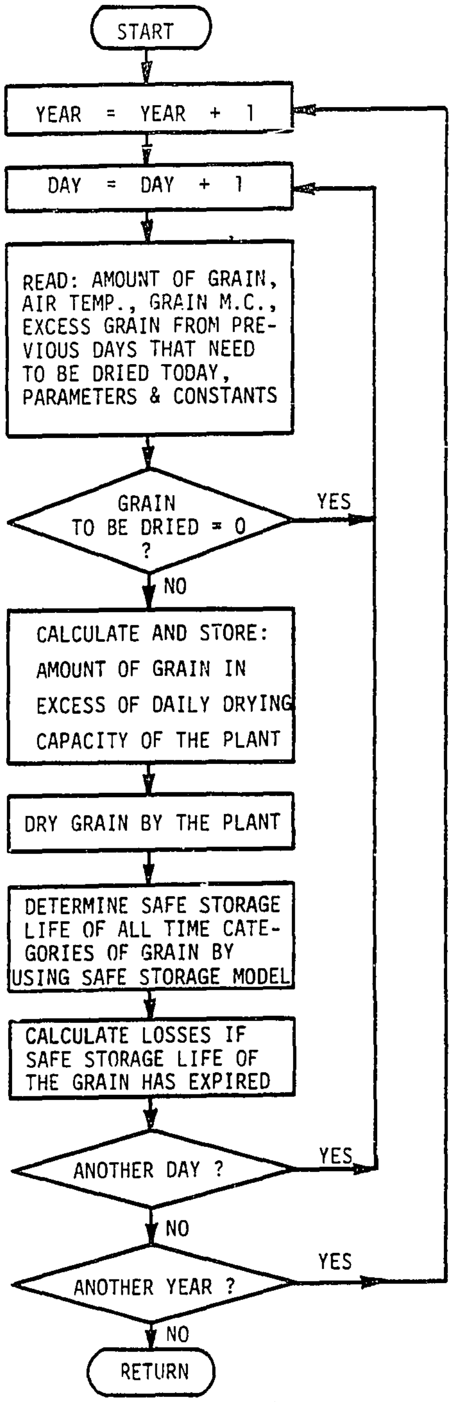

Figure 11 The Flow Diagram for Wet Grain Loss Due to the Limited Drying Capacity of the Plant--the GLOSS Subroutine

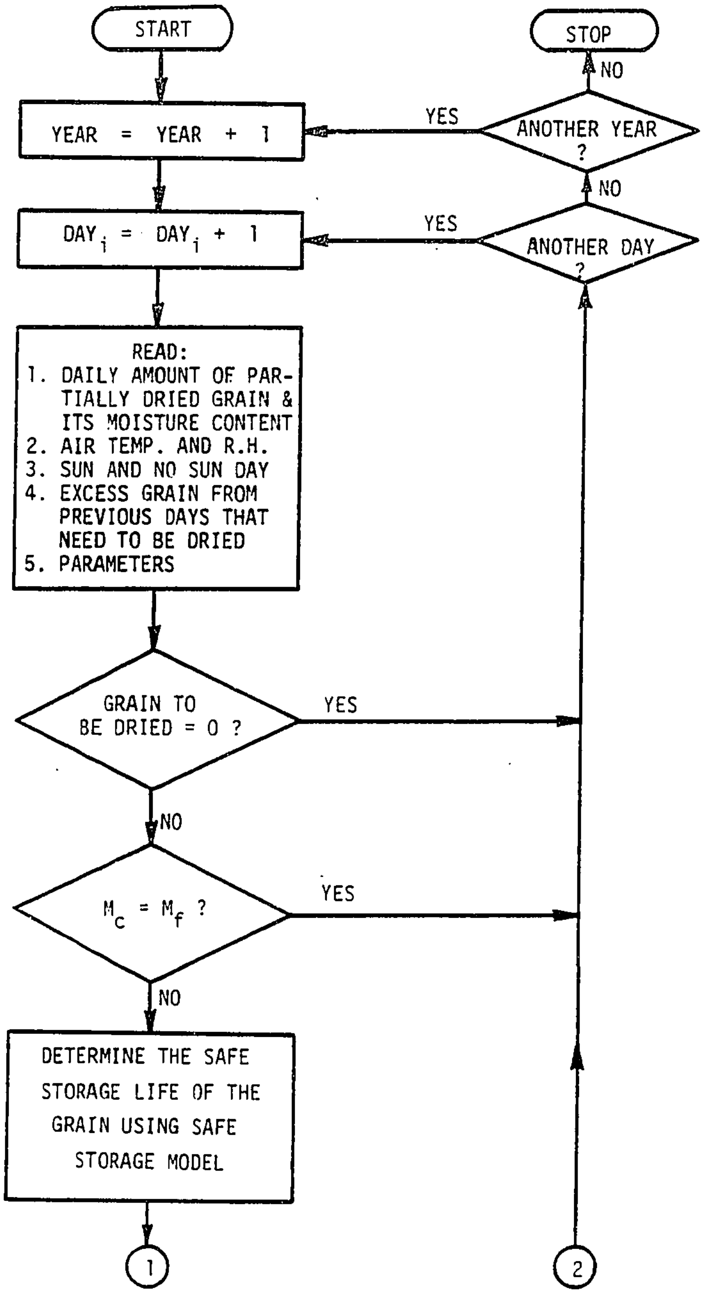

Figure 12 The Flow Diagram for Sundrying of Partially Dried Grain in the Processing Plant--the CSD1 Subroutine (cont.)

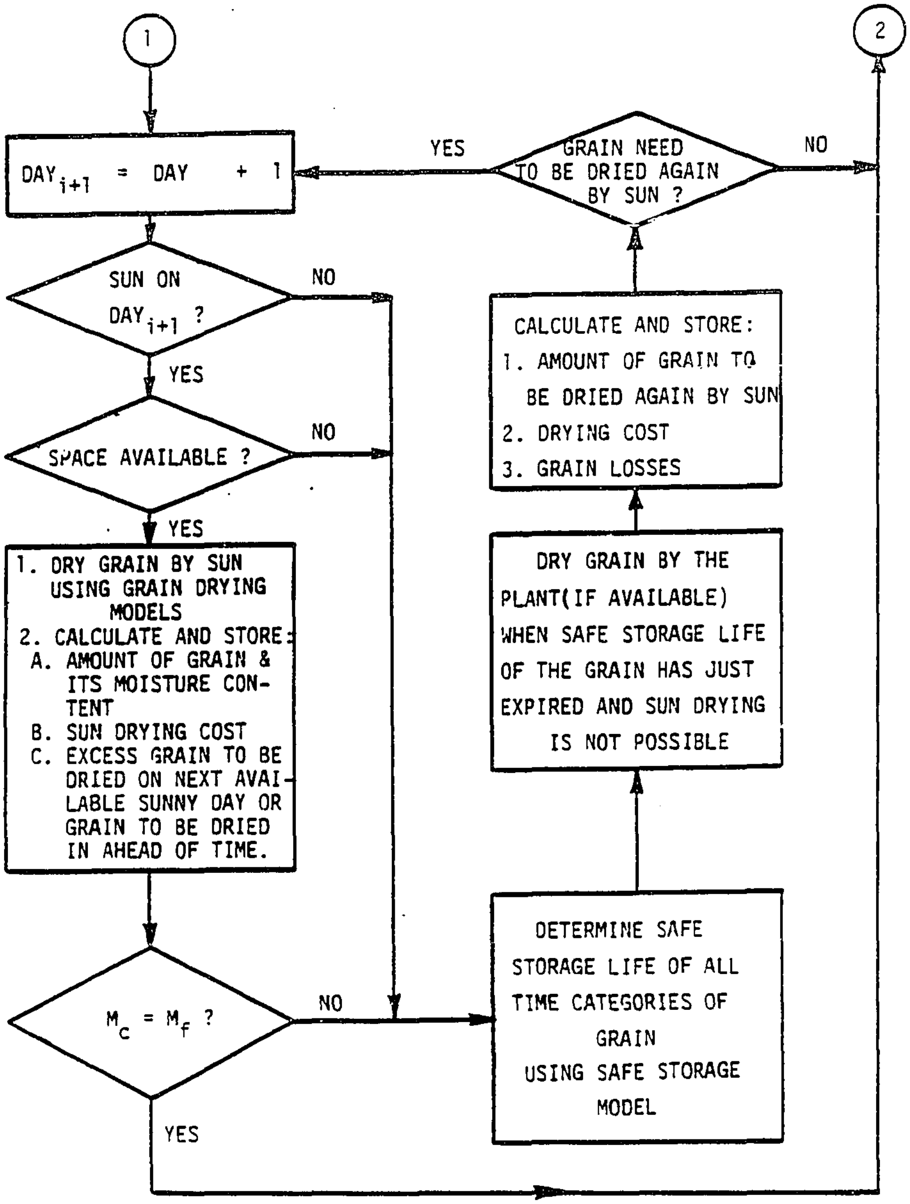

Figure 12 The Flow Diagram for Sundrying of Partially Dried Grain in the Processing Plant--the CSD1 Subroutine

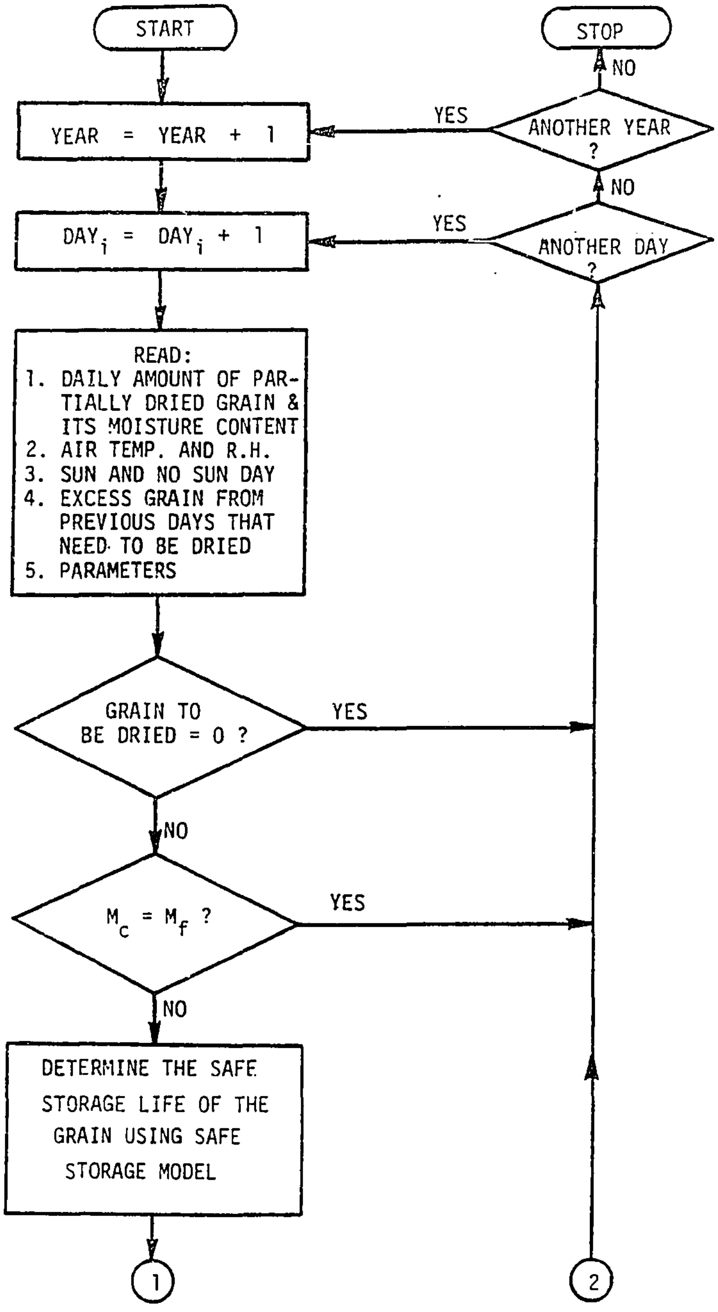

Figure 13 The Flow Diagram for Final Drying of Partially Dried Grain by the Plant--the CSD2 Subroutine (cont.)

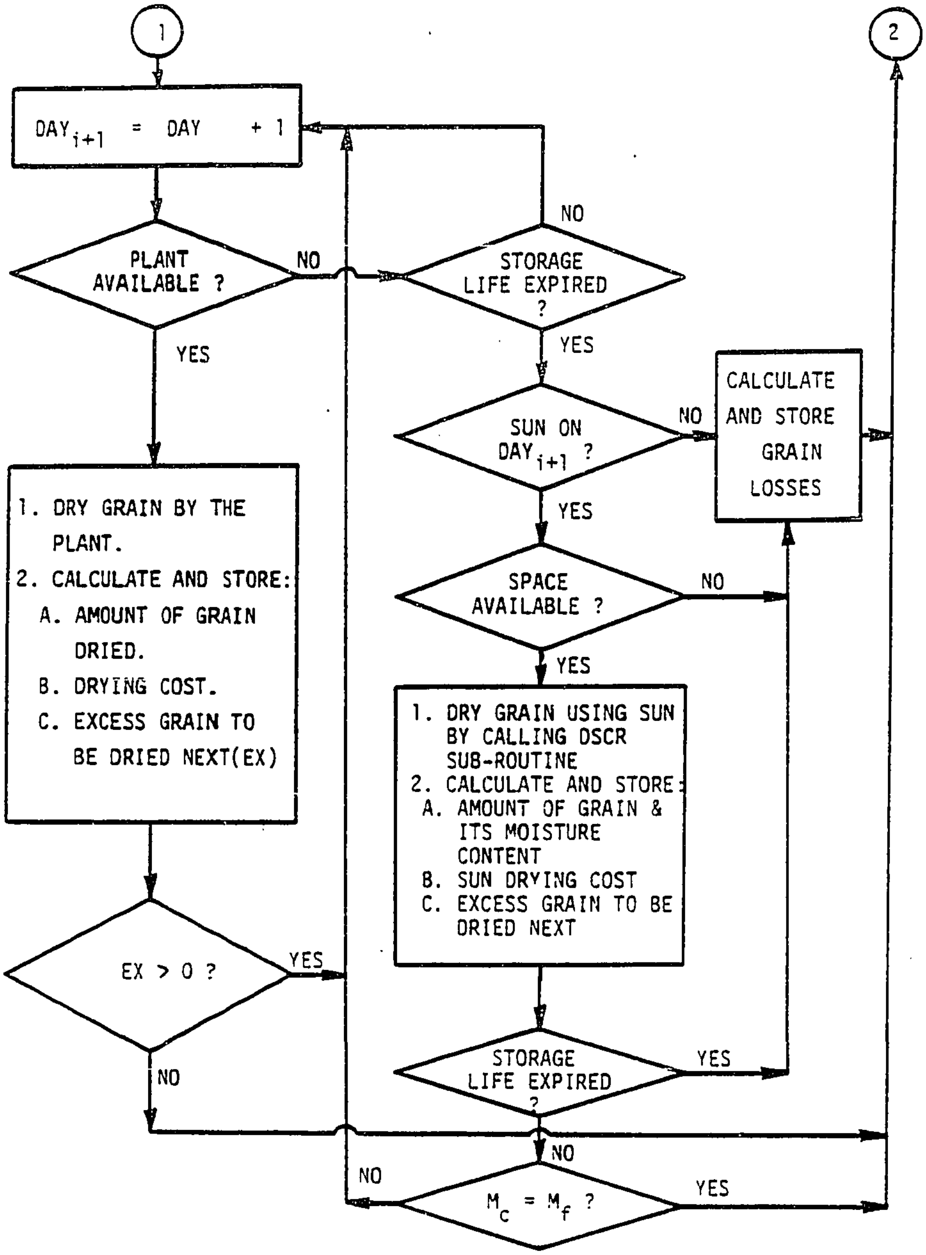

Figure 13 The Flow Diagram for Final Drying of Partially Dried Grain by the Plant--the CSD2 Subroutine

Due to lack of historical data or an appropriate model for estimation of stochastic variation of moisture content of the grain for the entire service area of the plant, a simple model based on the assumption of a uniform distribution has been used to simulate the moisture content of the grain at harvest.

The moisture content of the grain at harvest = minimum moisture content + (maximum moisture content - minimum moisture content) * random number

The mean maximum and the mean minimum moisture content of the grain (paddy) during harvesting season in this study are 30% db and 26% db respectively, which have been gathered from a research report of Habito and Duff (1979) (Appendix F). The program assumes moisture content of the grain to be at the maximum value, if a rainy day is observed prior to harvest.

3.2.2.3 Calculation of Grain Losses

Grain is considered a loss if it is kept beyond its safe storage period. The model for safe storage period of the grain determines the number of days that the grain could be stored safely. Grain losses may be observed due to the limited drying and storage capacities of the plant. The SPGDM prgram is capable of calculating these losses. In addition, it also calculates drying and handling losses as a fraction of the total processed grain. Figure 11, Figure 12, and Figure 13 show the logic behind the grain loss computation.

3.2.2.4 Model for Safe Storage Life of Grain

The temperature and moisture content together largely determine the safe storage life of the grain. proportion of kernels infected by fungi and the degree to which they are infected, Previous storage conditions, cleanliness of the grain, insect and mite infestation may also affect safe storage life of the grain. Based on the studies of Christensen (1974, p.354), a simple model for safe storage of the grain as a function of grain temperature and moisture content is developed.

$$\mathrm{Ln}\ S_L = 28.964 - \underset{(0.1462)}{6.6581}\ \mathrm{Ln}\ M_a - \underset{(0.0807)}{2.0393}\ \mathrm{Ln}\ T_g$$

$$(R2 = 0.9908,\ F = 1345.809,\ S_{y.x} = 0.1567)$$

where,

M_a = Average grain moisture content, % db

S_L = Safe storage life of grain, day

T_g = Grain temperature, ^0C

In general, this model can be rearranged as follows.

$$S_L = a\, M_a^u \, (T_a + t_g)^v$$

where,

T_a = Ambient air temperature, ^0C

T_g = $T_a + t_g$

t_g = Mean grain temperature above ambient, ^0C

a = $379.23 * 10^{10}$

u = -6.6581

v = -2.0393

The mean grain temperature above ambient for paddy, $t_g = 3$ ^0C, has been gathered from a research report by Koh (1981, p.83).

3.2.2.5 Model for Pressure Drop Through Grain

The pressure drop through a grain mass inside a drying bin depends on air flow rate, cross-sectional area of the bin, depth of the grain, grain moisture content, cleanliness of the grain and how loosely the grain is packed. A model of pressure drop through the grain has been estimated using the information available in the Agricultural Engineering Yearbook (1982, p.319). The estimated regression model for pressure drop per unit depth of wet paddy, loosely filled inside the dryer is;

$$\text{Ln } D_p = 8.2032 + \underset{(0.0176)}{1.1867} \text{ Ln } Q$$

$$(R^2 = 0.998,\ F = 4542.796,\ S_{y.x} = 0.0506)$$

where,

D_p = Pressure drop through grain per unit depth of grain, Pa/m

Q = Air flow rate through grain, m^3/m^2-s

The general form of the model may be as follows;

$$D_p = q\, Q^y$$

where,

q = A constant (for paddy, $q = 3652.62$)

y = A constant (for paddy, $y = 1.1867$)

3.2.3 Simulation Program for Financial Analysis (SPFA)

The purpose of this computer program is to evaluate the yearly income and cost during the simulated years. This program calculates fixed cost of the plant, cost due to grain loss, purchase cost of wet grain and partially dried grain and revenue from dry grain sale. It also determines investment cost of the entire plant which includes the initial cost of equipment, storage cost, cost of the concrete platform and the land cost. This program receives operating cost information such as the energy cost of grain drying and handling, cost due to the loss of wet grain and labor cost from the SPGDM program. Cost items are deducted from revenue to determine the net cash flow. The model used here to calculate the net cash flow is (Leung, 1977, p.42);

$$NCF = (TR - TC - D_e) * (1 - CT) + D_e$$

where,

CT = Corporate tax, decimal

D_e = Yearly depreciation on facilities and equipment, M/yr

NCF = Net cash flow, M/yr

TC = Total cost, M/yr

TR = Total revenue, M/yr

The Net Present Value (NPV) is used as the basis to determine the optimum size of the plant and to assess the profitability of the investment. The formula for determining net present value is:

$$NPV = \sum_{i=1}^{N} \frac{NCF(i)}{(1+r)^{i}} + \frac{PSV}{(1+r)^{N}} + \frac{VL}{(1+r)^{N}} - INF - LAN$$

where,

INF = Initial investment in equipment and facilities, M

LAN = Initial land value, M

N = Number of simulated year, yr

NCF(i) = Net cash flow for the year i, M

PSV = Plant salvage value at the end of Nth year, M

r = Interest rate, decimal

In addition, a Benefit Cost (B/C) ratio is calculated as;

$$B/C = \left[\sum_{i=1}^{N} \frac{NCF(i)}{(1+r)^{i}} + \frac{PSV}{(1+r)^{N}} + \frac{VL}{(1+r)^{N}}\right] \Big/ \left[INF + LAN\right]$$

Feasible investment is denoted by a positive Net Present Value or a B/C ratio greater than one at the end of the evaluation period. The formulae used by the Simulation Program for Financial Anaysis (SPFA) for fixed cost calculations are shown in Appendix C.

3.2.4 Model Operation Requirement

The main program with 23 subroutine subprograms written in FORTRAN 77 language was compiled, loaded and run on an IBM 3081 machine in the University of Hawaii Computing Center. Compilation of the program requires 524 K core and 3.45 seconds of computer time. Total time and core requirements are dependent on the way (alternative choice) the drying system would be analyzed. The execution of the program usually requires 4108 K of core and 6.66 seconds of computer time. Essentially no advanced computer knowledge is necessary to use this program. However, basic computer programming knowledge would be helpful in using the model.

4. THE MODEL OUTPUTS

4.1 System Design--Searching for the Optimum Combination of Facility Sizes

Since simulation does not provide any optimization power, searching for the optimum combination of drying and storage facilities of the plant has to be performed in an iterative manner. This usually requires a large number of simulation runs. The number of computer runs may be significantly reduced by intuitive judgement and good understanding of the system being analyzed. The model is capable of providing potential users an intuitive feeling of the situation involved and hence react accordingly.

To get the optimum capacities of the plant, initially, two reasonable levels of these important facilities of the plant were chosen--one for storage size, another for drying capacity of the plant. Both levels were selected intuitively, based on prior information on the pattern of the grain harvest. Keeping the storage size fixed (in this case 500.0) the dryer capacity was varied under a specific weather pattern (weather pattern 1*). The computer program

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* See Appendix E for definition of weather pattern

was run for each level of the dryer capacity until the maximum Net Present Value (NPV) of cash flow was reached. Table 4 shows that this was achieved at the dryer capacity of 31.5 m^3/8 hr. The grain loss information of the model output was adequate enough to indicate which direction the facility size should be varied. Then, keeping the drying capacity fixed at 31.5 m3/8 hr, the storage level was varied until the maximum Net Present Value (NPV) of cash flow was reached. For the specific weather pattern, a potential optimum drying and a potential optimum storage capacity were obtained at 31.5 m^3/8 hr and 545.5 m^3, respectively. It was observed that the storage capacity had a very insignificant effect on the NPV of cash flow (Table 4). This reveals the fact that revenue loss due to limited storage capacity is negligible. The revenue loss has been defined here as a loss of revenue when the plant management has to sell their dry grain to the market at a lower price immediately after drying, due to limited storage capacity. Keeping the storage level fixed at 545.5 m^3, eight potential optimum levels of drying capacities were obtained for eight different weather patterns (Table 5). The effects of weather on drying capacities and NPVs at a storage capacity of 545.5 m^3 are shown in Figure 14. The variances of NPVs (NPVs are calculated for eight different weather patterns) corresponding to each of the potential optimum drying capacities were calculated. The optimum drying capacity, 37.0 $m^3/8$ hr, was found at the minimum variance of NPVs (Table 5). In other words, the grain processing plant with the optimum drying capacity of 37.0 $m^3/8$ hr had minimum weather effects. Then keeping the optimum drying capacity fixed at 37.0 $m^3/8$ hr along with the corresponding weather pattern (weather pattern 5), the storage capacity was varied until the maximum NPV of cash flow was reached. The optimum storage capacity was obtained at 579.0 m^3 (Table 6). The optimum combination of drying and storage capacities of the drying plant and the effects of change of drying capacity are shown in Figure 15. The figure explains the fact that the grain loss decreased gradually as the drying capacity increased up to the optimum point. Thus, the Net Present Value (NPV) of the cash flow gradually increased up to the point of optimization. However, it fell beyond this point. This was due to the higher unit cost of the dryer than the value of the grain saved. For the same reason, it was observed that grain loss persisted even at the optimum capacity of the plant (Appendix K). Other design information at the optimum capacity of the plant are shown in Appendix K. The Net Present Value (NPV) of cash flow and the Benefit Cost (B/C) ratio indicated that investment in a grain (paddy) drying plant in Los Banos under risky weather conditions was economically feasible.

Table 4 The Net Present Value (NPV) of Cash Flow Corresponding to the Drying and Storage Capacities of the Plant for Weather Pattern 1

Drying Capacity (m^3/8 hr)	Storage Capacity (m^3)								
	500.0	540.0	545.0	545.4	545.5	545.6	546.0	550.0	570.0
28.00	413817.44				416907.19				
29.00					424260.12				
30.00	429948.31				433260.00				
31.00	434922.94				438322.31				
31.25	436980.44				440402.00				
31.40	437268.50			440707.25	440703.19	440699.75			
31.50	438163.62	441573.94	441602.25	441604.56	441604.87	441603.62	441587.69	441432.31	440537.19
31.60	437681.56			441122.12	441122.12	441123.19			
31.75	437526.69				440967.12				
32.00	436329.19				439768.87				
32.50					439088.44				
33.00	433389.44				436829.12				
34.00					434700.12				

Table 5 The NPVs Versus Potential Optimum Drying Capacities at Different Weather Patterns for a Storage Capacity of 545.5 m^3

	Weather Pattern of 15 Simulated Years								
	1	2	3	4	5	6	7	8	
% of no sunny day during harvesting seasons	39.57	41.44	41.21	41.74	40.30	43.18	41.82	41.82	
% of harvest day during harvesting seasons	70.91	66.97	67.88	66.52	69.24	66.97	68.48	67.05	
Total no. of no sun-no sun sequence during harvesting seasons	240	251	255	255	256	276	276	285	
Maximum no. of successive no sun days during harvesting seasons	8	9	9	9	10	11	12	15	
Potential optimum drying capacity (m^3/8 hr)									Variance of NPVs
31.50	441604.87	434348.19	463530.87	525085.31	384257.50	512300.44	319446.12	399002.31	$4.59*10^{9}$
34.00	434700.12	466452.12	484476.23	529976.22	404919.69	528989.33	358778.15	425561.19	$3.59*10^{9}$
35.00	430253.12	465695.75	487330.87	531357.87	407658.25	530576.75	372279.31	432745.62	$3.26*10^{9}$
35.50	427800.00	463865.94	485621.28	531404.87	411560.78	531112.18	395882.06	433200.08	$2.69*10^{9}$
37.00	419414.37	462461.06	483322.69	527382.69	415283.06	533210.06	402679.00	434694.56	$2.57*10^{9}$
37.50	416718.00	460952.19	481864.69	525171.69	414423.56	533762.19	404716.56	435892.19	$2.60*10^{9}$
40.50	393763.44	442324.37	468896.19	520461.19	393355.94	528367.37	410704.75	440887.19	$2.78*10^{9}$
42.00	380821.19	428993.31	460374.94	512204.94	383998.31	523723.44	410127.12	442298.69	$2.89*10^{9}$

Table 6 The Net Present Value (NPV) of Cash Flow Corresponding to the Drying and Storage Capacities of the Plant for Weather Pattern 5

	Storage Capacity (m^3)									
	545.5	570.0	574.0	576.0	578.0	$\boxed{579.0}$	580.0	582.0	584.0	588.0
Drying Capacity (m^3/8 hr)										
31.0						376198.44				
33.0	395355.06					396078.19				
35.0	407658.25					408703.81				
36.0	413289.44					414855.12				
$\boxed{37.0}$	415283.06	416544.31	416712.44	416797.44	416881.56	$\boxed{416888.31}$	416856.94	416796.69	416736.00	416616.06
38.0	411329.62					413059.06				
39.0						405780.06				
40.0	396564.06					398543.87				
41.0						392021.50				
43.0	375273.25					377066.25				

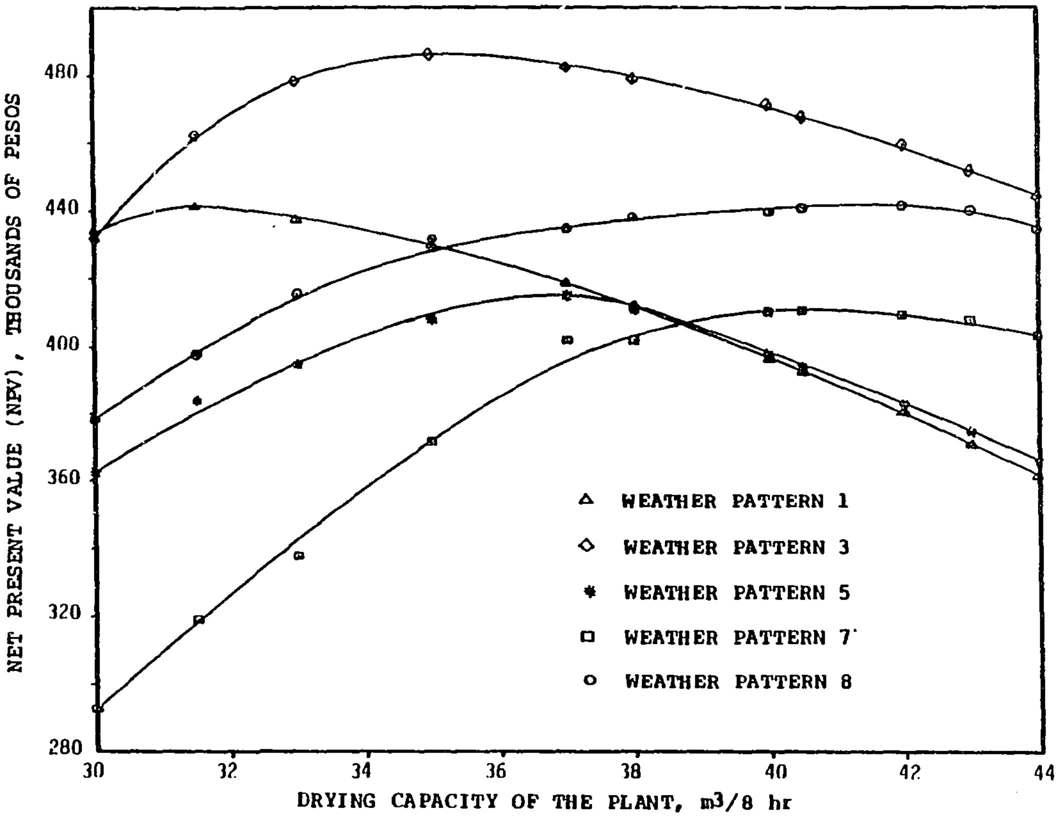

Figure 14 The NPVs Versus Drying Capacities for Different Weather Patterns at 545.5 m3 of Storage Capacity

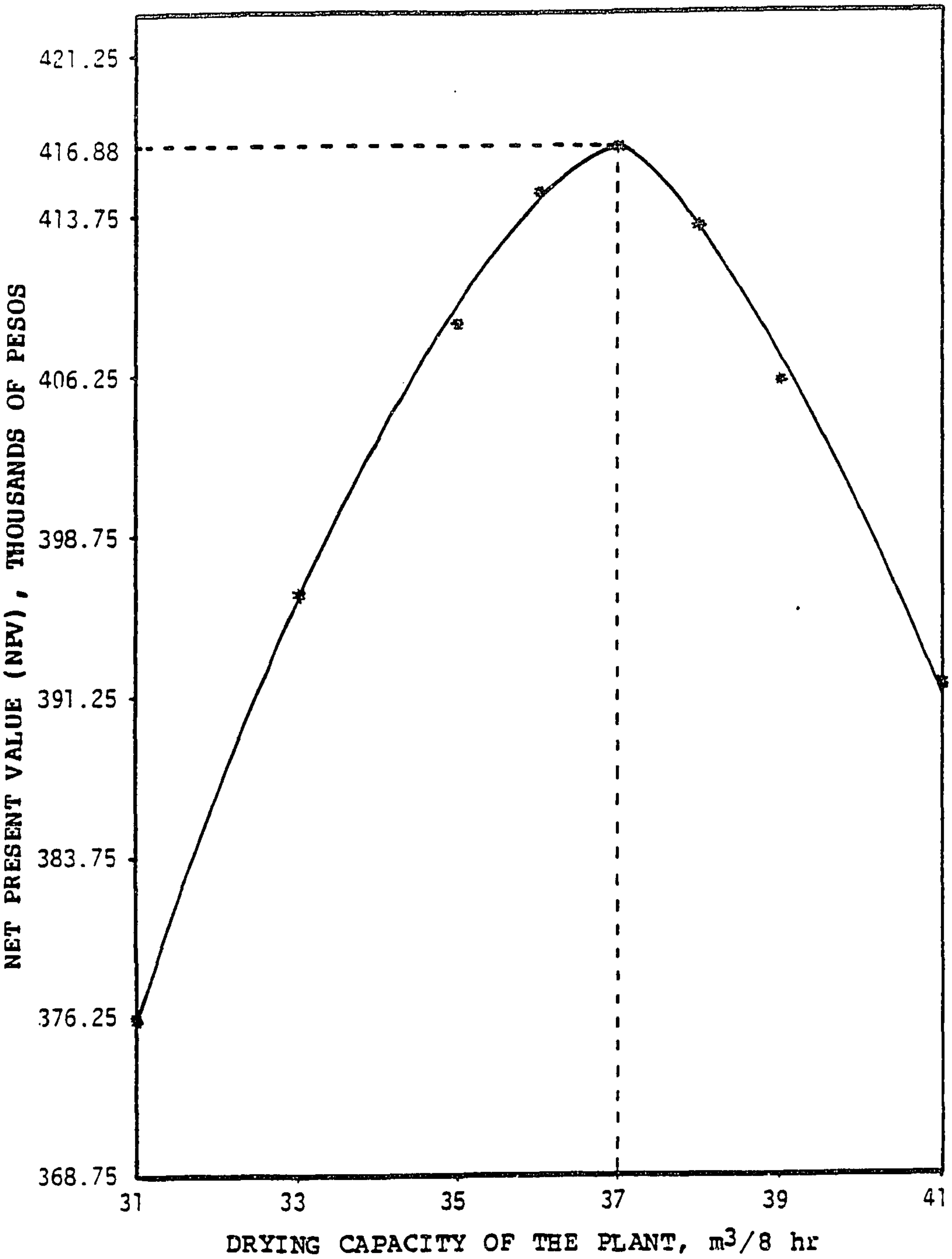

Figure 15 The NPVs Versus Drying Capacities for Weather Pattern 5 at 579.0 m^3 of Storage Capacity

4.2 Sensitivity Analyses and Model Verification

Sensitivity analyses of the model with respect to several important controllable and uncontrollable variables of the system were performed primarily for two reasons. First, to study the behavior of the system due to change of some uncontrollable variables involved in the system and second, to study the outputs of the model at different levels of alternative variables thereby verifying the model. Although a large number of variables and parameters are involved in the grain drying system, only a few important variables may significantly affect the system. The behavior of the system to important alternative variables and parameters as studied here indicated that the developed model is adequately verified and operational.

The effects of change of drying capacity on grain loss were evaluated at a fixed storage level of 579.0 m^3 (optimum size) for different drying capacities. The results (Figure 16 and Figure 17) show that as the dryer capacity increased the grain loss decreased. On the other hand, the investment cost increased as the dryer capacity increased (Figure 17). The same kind of effects on revenue loss due to change of storage capacity at a fixed drying capacity of 37.0 $m^3/8$ hr (optimum size) were observed (Figure 18).

The interest rate of 11% was gathered from a report of

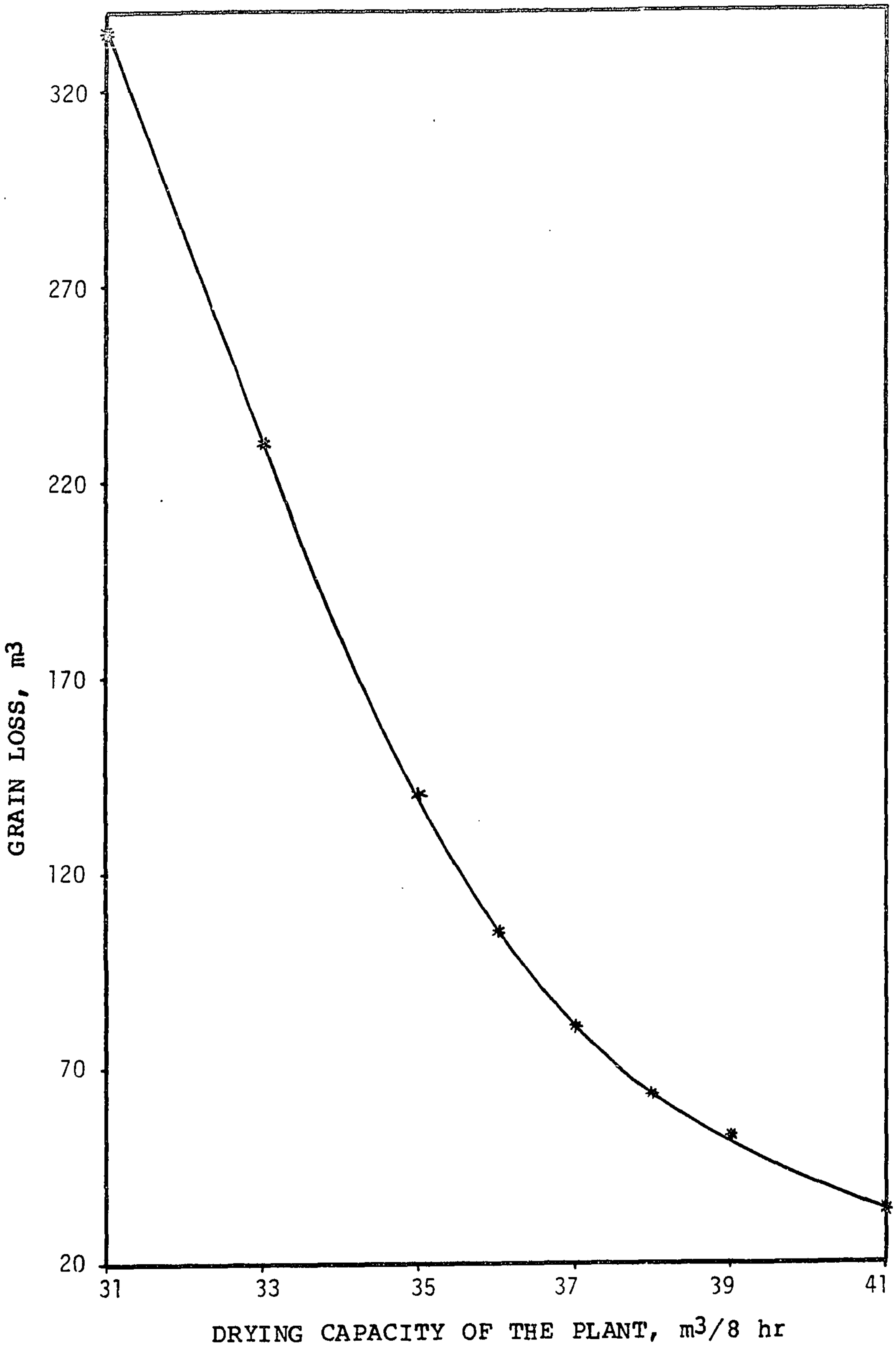

Figure 16 Grain Losses Versus Drying Capacities for Weather Pattern 5 at 579.0 m^3 of Storage Capacity

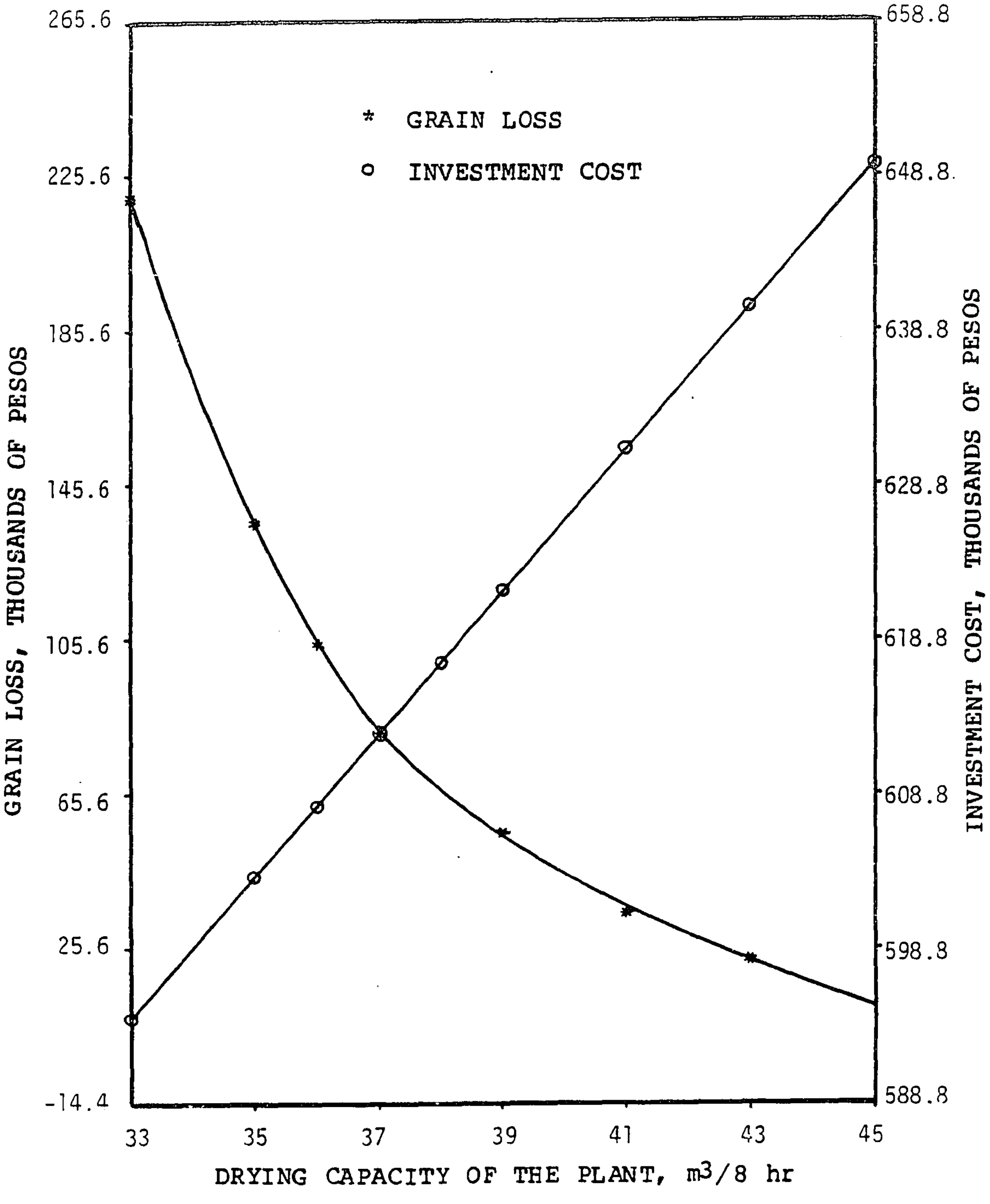

Figure 17 Grain Losses and Investment Costs Versus Drying Capacities for Weather Pattern 5 at 579.0 m3 of Storage Capacity

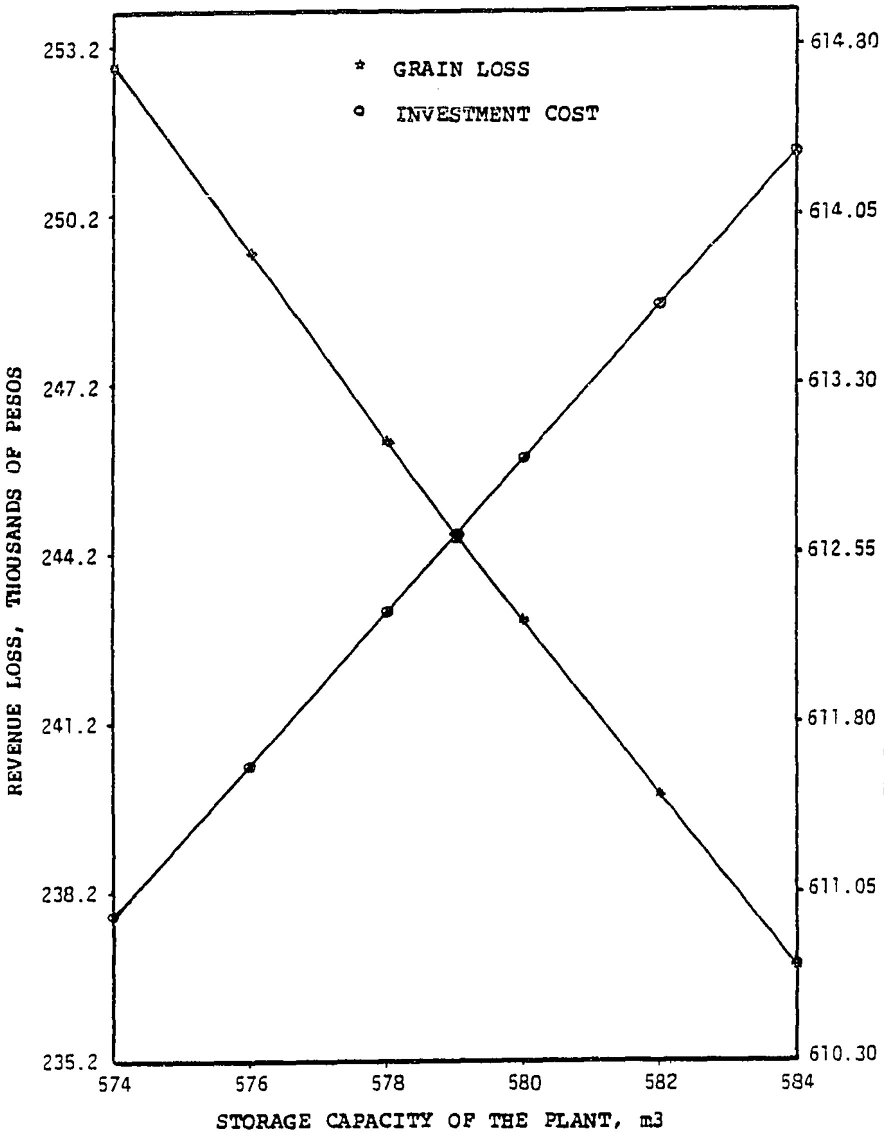

Figure 18 Revenue Losses and Investment Costs Versus Storage Capacities for Weather Pattern 5 at 37.0 m3/8 hr of Drying Capacity

the Asian Development Bank (1982) and was utilized in this study for optimization of the plant. The effects of interest rates on the grain drying system were evaluated at five different levels of interest rates. The results in Table 8 show that the interest rates played a significant role in the plant economy. Thus, careful attention must be paid in using the interest rate while analyzing the grain drying systems. Table 9 shows the effects of proportional decrease and increase of the market price for all moisture categories of the grain (paddy). The economic performance of the plant was highly effected due to the change of market price of the grain. The NPV and B/C ratio increased as the market price of paddy increased. In other words, the drying plant became financially more efficient as the market price of the grain increased. On the other hand, the NPV and the B/C ratio decreased as the grain price decreased. This indicated that the plant became more uneconomical as the market price of paddy decreased.

One of the most important variables involved in a grain drying system is the land productivity. The results shown in Table 10 indicate that land productivity had a significant effect on economic performance of the plant. As the grain yield decreased, the NPV also decreased. This revealed the fact that the plant was underutilized--the fixed cost of the plant was higher. On the other hand, the NPV of cash flow increased as the grain yield increased, however, it started declining with further increase in grain yield. Again, this explained the fact that the plant had inadequate capacity with further increase in grain yield and consequently more grain losses were incurred. The same kind of effects were observed due to the change of the service area of the plant (Table 11). The effects of change of the service area of the plant indicate that the model is not only suitable for designing a centralized grain drying system but also appropriate for designing a dryer for an individual farm.

Another important variable that may affect designing a grain drying plant is the use of individual dryers within the service area of the plant. The results shown in Table 12 clearly indicate that establishment of a drying plant might not be feasible if there were individual dryers presently in use inside the service area of the plant.

Perhaps, the most important uncontrollable variable affecting design and operation of a grain drying plant in the developing countries is the weather. The model itself is capable of simulating the stochastic nature of weather elements. The simulated results due to change in the number of sunny days during harvesting seasons are presented in Table 13. The results show that design and economic performance of a drying plant were highly affected by weather. Furthermore, Table 5 indicates that as the weather

Table 7 The Optimum Drying and Storage Capacities When Grain Loss is Zero

Grain loss (m^3)	PV(NCF) (Peso)	NPV (Peso)	B/C	Dryer capacity (m^3/8 hr)	Storage capacity (m^3)	Investment cost (Peso)
0.0	976522.75	169113.31	1.20	49.00	990.75	807409.44

Table 8 Effects of Different Interest Rates

	Interest Rates (%)				
	7	9	11*	13	15
PV(NCF)	1531947.00	1246665.00	1029524.50	861172.19	728508.69
NPV	919310.81	634028.81	416888.31	248536.00	115872.50
B/c	2.48	2.02	1.67	1.40	1.18

* This figure has been used in the optimization of the plant

Table 9 Effects of Change of Market Price of All Moisture Categories of the Grain (Paddy)

% Decrease/increase in market price of the grain(paddy)	PV(NCF) (Peso)	NPV (Peso)	B/C
-40	425667.12	-186969.06	0.69
-30	560772.06	-51864.12	0.91
-20	708216.06	95579.87	1.15
-10	862586.19	249950.00	1.40
0*	1029524.50	416888.31	1.67
10	1220060.00	607423.81	1.98
20	1433490.00	820853.81	2.33
30	1660993.00	1048356.81	2.70
40	1895908.00	1283271.00	3.08

* This figure has been used in the optimization of the plant

Table 10 Effects of Change of Land Productivity

	Grain Yield (m^3/ha)				
	2.0	3.0	3.57*	5.0	6.0
PV(NCF)	421183.37	822903.50	1029524.50	1156427.00	1027556.00
NPV	-174299.56	216544.44	416888.31	528043.12	388159.75
B/C	0.70	1.35	1.67	1.83	1.60

* This figure has been used in the optimization of the plant

Table 11 Effects of Change of Service Area of the Plant

	Service area of the plant (actual productive land) (ha)				
	100	300	500*	700	900
PV(NCF)	-75888.62	475553.44	1029524.50	1156804.00	934398.75
NPV	-658083.00	-121396.81	416888.31	528442.12	290311.19
B/C	-0.12	0.79	1.67	1.83	1.44

* This figure has been used in the optimization of the plant

Table 12 Effects of Use of Individual Grain Dryers Within the Service Area of the Plant

	Total daily drying capacity of the dryers presently used within the service area of the plant, TDD (m^3/day)			
	0.0*	10.0	20.0	30.0
PV(NCF)	1029524.50	788377.12	553311.56	331516.69
NPV	416888.31	179236.94	-52332.62	-270631.50
B/C	1.67	1.29	0.91	0.55

* This figure has been used in the optimization of the plant

Table 13 Effects of Change of Weather : Change in the Number of Sunny Days During Harvesting Seasons

	Critical level of solar radiation for determination of sun-no sun day, B (Cal/cm^2/day)				
	More sunny days		Original	Less sunny days	
	150.0	200.0	250.0*	450.0	650.0
PV(NCF)	624187.75	774743.37	1029524.50	1783855.00	-537450.94
NPV	11551.56	162107.19	416888.31	1171218.00	-1150087.00
B/C	1.01	1.26	1.67	2.89	-0.86

* This figure has been used in the optimization of the plant

pattern changed, the potential optimum drying capacity changed. A relationship between the potential optimum drying capacity and the weather pattern was obtained and is expressed by a regression model as follows.

$$D_{pr} = -0.36096 + \underset{(0.0735)}{0.11317\ N_s} + \underset{(0.5001)}{0.7098\ N_m}$$

$$(R^2 = 0.9253,\ F = 30.95,\ S_{y.x} = 1.10)$$

where,

D_{pr} = Potential optimum drying capacity, $m^3/8$ hr

N_m = Maximum number of successive no sunny days during harvesting seasons of entire simulated period.

N_s = Number of sequences of no sun today and no sun tomorrow during harvesting seasons of entire simulated period.

The values of N_s and N_m both had positive effects on the potential optimum drying capacity of the plant. However, Table 5 shows that the percentage of no sunny days during harvesting seasons of the entire simulated period had little effect on potential optimum drying capacity of the plant. It reveals the fact that the optimum drying capacity largely depends on the sequence of successive no sunny days rather than total number of no sunny days. Thus, in designing a grain drying plant, especially in developing countries, the stochastic nature of weather must not be ignored.

The design and economic operation of the processing plant might also be affected by management policies. One of the important management alternatives is to dry grain partially (by the plant) to a certain level of moisture content. The effects of change of moisture content level for partial drying of the grain were studied with six different moisture levels. The maximum NPV ·as found at 416888.31 pesos* (Table 14), when grain was dried partially by the plant to a level of 20% db. However, the global maximum NPV was obtained at 754880.12 pesos*, when grain was dried at once by the plant to the safe storage moisture level of 14% db. This maximum NPV was observed mainly due to the lower investment cost, consequently the lower fixed cost of the plant (note: in this case no investment cost of concrete platform for natural sundrying of the grain was needed) (Table 14).

The farmer's decision to sell grain to the processing plant also had a significant effect in design, operation and economic performance of the plant (Table 15). The symbol

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* 1982 value, US $ 1.00 = 8.69 pesos; source: Asian Development Bank (1982)

KFD, as shown in Table 15 is a decision indicator of grain sale by the farmers to the plant management. The value KFD = 1 means that the farmers wait only one future day (total two days) to have a sunny day after harvest, before they sell their grain. The value KFD = 2 means that the farmers wait only two future days (total three days) to have a sunny day after harvest, before they sell their grain. However, statistics (Christensen, 1974, p.354) show that in some cases grain is subjected to total loss within 24 hours after harvest. Of course, it largely depends on grain temperature, ambient temperature and the moisture content of the harvested grain. Thus, the probability of selling wet grain before it deteriorates is higher in the former (KFD = 1) than the later (KFD = 2).

A continuous weather data of 25 years (1959 to 1983) from Los Banos, Philippines has been used to study the behavior of a grain drying system. However, in the developing world, it is not unlikely to observe discontinuous weather data throughout a fairly long period of time. The effect of the use of discontinuous data on the behavior of the system has also been studied. Weather data of 3 years (1960, 1974 and 1982) was selected randomly and was used to study the behavior of the system. The appropriate monthly probability distributions (Table 16 and Appendix D) were fitted to these discontinuous air temperature data using

UNIFIT (Law et al., 1983). The relative humidity of air was generated by using fitted regression models (Table 17). Table 2 and Table 16 indicate that probability distributions for the month of January, June, July, August, September, November and December were found to be different. The use of discontinuous weather data (input data) had little effect on economic performance of the grain drying system. The NPV changed from 416888.31 pesos to 415684.19 pesos, the benefit-cost ratio changed from 1.67 to 1.68 (Table 18). Table 18 also indicates that no significant differences of NPVs were observed between direct use of historical weather data and the use of fitted distributions with continuous weather data. The effects of change of some management variables have also been studied and the results are shown in Table 19 and Table 20. These tables also indicate that the developed model is adequately verified.

Table 14 Effects of Change of Moisture Content Level for Partial Drying of the Grain (Paddy) by the Plant

	Moisture Content of the Grain (Paddy) for Partial drying by the plant (% db)					
	14*	16	18	20**	22	24
PV(NCF)	1180759.00	963006.25	1011328.69	1029524.50	967648.50	775763.56
NPV	754880.12	350374.94	398694.94	416888.31	355009.87	163122.50
IC	425878.87	612631.31	612633.75	612636.19	612638.62	612641.06
FC	988273.90	1308938.20	1308944.60	1308952.10	1308958.50	1308965.10
VC	979411.71	1193408.10	1071667.80	1028211.90	1181840.60	1664065.20
B/C	2.76	1.56	1.64	1.67	1.57	1.26
A_1	0.00	0.22	0.22	0.22	0.22	0.22
Q	0.049	0.042	0.036	0.031	0.031	0.035

* Safe moisture content for storage
** This figure has been used in the optimization of the plant

Table 15 Effects of Change of Farmers Decision to Sell Grain to the Processing Plant

	KFD*	
	1**	2
PV(NCF)	1029524.50	415877.50
NPV	416888.31	-196758.69
B/C	1.67	0.68

* KFD is the number of future bad weather day(s) that farmers may wait for sundrying before they decide to sell their grain to the plant

** This figure has been used in the optimization of the plant

Table 16 The Fitted Probability Distribution to Daily Air Temperature (^{0}C) in Los Banos, Philippines for 1960, 1974 and 1982.

Month	Fitted Distribution	Location Parameter	Scale Parameter	Shape Parameter	CHI-Square Value	Degree of Freedom
January	Normal	24.7502	1.134970	-	14.0322	15
February	Weibull	0.0000	26.012400	24.53820	13.5238	13
March	Weibull	0.0000	27.346100	26.82450	16.3548	15
April	Weibull	0.0000	28.877400	37.30410	19.1999	15
May	Weibull	0.0000	29.071300	31.77100	8.9999	15
June	Weibull	0.0000	28.941500	27.46600	18.8000	15
July	Logistic	27.7225	0.479180	-	8.2257	15
August	Extreme Value Type A	28.0065	0.978599	-	19.0644	15
September	Normal	27.3307	0.837651	-	7.5999	15
October	Weibull	0.0000	27.334000	31.50670	15.9677	15
November	Extreme Value Type A	26.9018	0.77936	-	13.6000	15
December	Logistic	25.9447	0.61264	-	20.9999	15

Table 17 The Fitted Regression Model to Weekly Air Relative Humidity and Temperature in Los Banos, Philippines for 1960, 1974 and 1982

Month	Regression Model	R^2	F	$S_{y.x}$
January to March	$RH = 140.90 - 2.3597\ T$ (0.523)	0.6486	20.305	1.9417
April to September	$RH = -15.85 + 2719.70\ T^{-1}$ (515.86)	0.5366	27.796	2.0389
October to December	$RH = 99.87 - 417.14\ T^{-1}$ (197.36)	0.5250	10.288	1.6736

RH = Relative humidity of air (%) ; T = Air temperature (^{0}C)

Table 18 Effects of Use of Generated Weather Data Using Fitted Probability Distributions

	25 years of continuous data		3 years of discontinuous data
	KWD**		
	1***	2	
PV(NCF)	1029524.50	1015800.00	1018491.81
NPV	416888.31	403163.81	415684.19
B/C	1.67	1.65	1.68

** KWD is a decision indicator for use of weather data. KWD = 1 means historical weather data is used directly. KWD = 2 means historical weather data is used to generate daily temperature and relative humidity of air using fitted probability distributions.

*** This figure has been used in the optimization of the plant

Table 19 Effects of Change of Decision to Sell Dry Grain (Paddy) by the Plant Management

	KSY**	
	1***	2
PV(NCF)	1029524.50	-490941.81
NPV	416888.31	-1103578.00
B/C	1.67	-0.78

** KSY is a management indicator for dry grain sale to the market. KSY = 1 means all dry grain is sold out at the end of each drying season. KSY = 2 means all dry grain is sold out only at the end of each year.

*** This figure has been used in the optimization of the plant

Table 20 Effects of Change of Policy for Final Drying of the Partially Dried Grain (Paddy)

	KSD*	
	1**	2
PV(NCF)	1029524.50	977979.50
NPV	416888.31	365343.31
B/C	1.67	1.59

* KSD is a policy indicator for drying of the partially dried grain. KSD = 1 means partially dried grain is dried by the plant. If plant is not available, it is dried finally by sun. KSD = 2 means partially dried grain is dried by natural sundrying. If sun is not available, it is dried finally by the plant.

** This figure has been used in the optimization of the plant

5. MODEL FLEXIBILITY AND APPLICATION

5.1 Model Flexibility

The simulation model was coded into a main program with 23 subroutines in FORTRAN 77 language. It is easy to add, delete or modify a subroutine whenever necessary. Regarding the generation of air temperature and relative humidity, the model offers two alternative choices;

a) Use of historical ambient temperature and relative humidity data directly as a substitute of generation.

b) Generation of air temperature and relative humidity using fitted probability distributions.

The later is time consuming and costly. Appropriate probability distributions must be fitted to the historical data for each location. However, an optional submodel has been incorporated into the model to make the model operational in a locality where discontinuous or missing historical data exists.

The model has been developed so that possible alternative management strategies could be easily analyzed. For example, the model could provide the answer to the question whether it would be better to dry wet grain partially up to a certain moisture level or to dry grain up to the final (safe) moisture level. The system can also be evaluated under the farmers' alternative decision to sell wet grain to the processing plant. It is flexible enough to evaluate a drying system in any location of the developing world where grain is harvested under adverse weather conditions. The model can be expanded to include other post-harvest operations by adding new submodels. No major changes of the program are needed. For instance, an integrated grain threshing, drying, and milling complex could be analyzed by adding new subprograms for threshing and milling of the grain into the program.

5.2 Application of the Model

System simulation can be viewed as a deliberate and systematic abstraction of the salient features from the real system into a formal computer program so that analysis of this abstracted system can assist in providing answers to real world problems. Experimentation with both new and existing grain drying systems can be made on a computer. The model could be used as research, management and feasibility study tool. It could also be used for redesign, management and economic analysis of existing drying plants. The model may be successfully applied to;

1. Design of a grain drying and storage system, especially suitable for developing countries.
2. Feasibility study of a drying and storage complex.
3. Redesign and evaluation of an existing grain drying plant.
4. Evaluation of a drying and storage system through possible management alternatives and drying parameters.
5. Estimation of total investment cost of a drying and storage plant.
6. Drying cereals such as paddy, wheat, corn, sorghum, soybeans etc.
7. Design and evaluate a threshing, drying, milling and storage complex through minor modification.

6. SUMMARY AND CONCLUSIONS

The complex interrelationship of a centralized grain drying system has been analyzed and abstracted into an operational, flexible and general simulation model for economic decision-making.

The model has been developed in such a way that it adequately represents the complex interrelationship of both stochastic and deterministic elements of a grain drying system (Objective 1). Important economic, weather and physical elements, as well as their interactions, could be analyzed simultaneously as indicated by the outputs of the model. Table 6 shows that the optimum level of capacities of the paddy drying system were obtained at $D_r = 37.0\ m^3/8$ hr and $Z = 579.0\ m^3$ (Objective 2). Essentially a simulation model is a powerful tool to analyze a complex system with a large number of alternative choices. The developed simulation model is quite capable of studying the behavior of a grain drying system at various levels of variables and alternative choices. The paddy drying system, as analyzed here, involves a large number of variables. Because of the computing cost, only a few important alternative choices of the model have been studied and are shown in Section 4.2. Evaluation of the system with respect to other possible alternatives could also be performed (Objective 3). The developed model is general enough (objective 4) so that adaptation to other similar grain drying systems at any location is possible. In analyzing similar grain drying systems, the only change needed is the input grain parameters. No change of the model or the program is needed. Thus, the cost and time involved in analyzing a particular grain drying system can be significantly reduced by using the model. In addition, the model can be successfully applied to evaluate an on-farm grain drying facility. Although the model has been developed by focusing on the developing areas of the world, it could also be used to evaluate a grain drying system in a developed country. The computer program of the model has been so designed that potential users with basic computer experience can use the model. Following the steps of using the model (Appendix J) potential users can easily handle the model and analyze the results.

The optimal drying capacity, storage size and benefit cost ratio for the application were 37.0 m^3/8 hr, 579.0 m^3 and 1.676, respectively. Appendix K shows that the minimum and the maximum plant capacity utilization per year were obtained at 56% and 76%, respectively. The plant was found to be operating at its full capacity ranging from 1 to 20 days per year. The unit cost of drying (in 1982 value) using a kerosene-fed dryer was found to be 32.06 pesos/m^3 (US\$3.68/m^3) or 56.02 pesos/ton (US\$6.44/ton). The grain saved by establishing the plant ranged from 693.30 m^3/yr to 1662.09 m^3/yr. The paddy drying system was evaluated for a plant life of 15 years. The payback period of the investment was approximately 5.75 years. The Net Present Value (NPV) and the Benefit Cost (B/C) ratio at the optimum plant size (Appendix K) indicated that the investment in the grain (paddy) drying plant in Los Banos of the Philippines under risky weather conditions was feasible. Since the plant was designed by considering the most important factor of grain drying in a developing country, that is, the stochastic nature of weather, it might be concluded that the investment in this processing plant had a minimum weather risk. The optimum combination of drying and storage capacities of the plant were obtained by maximizing the NPV of cash flow. In other words, the optimum combination of the facilities was obtained from a plant investment point of view. However, the model is quite capable of obtaining another combination of optimum drying and storage capacities of the plant from a social welfare point of view. That is, another combination of the facilities of the plant could be found at zero grain loss. This was found at the dryer cpacity of 49.0 m^3/8 hr and the storage capacity of 990.75 m^3 (Table 7). The NPV and the B/C ratio indicated that the investment on the project with a view to minimize grain loss was also feasible and had minimum weather risk.

The model has been simplified by assuming that the farmers sell their grain to the processing plant when the weather is not favorable for on-farm sundrying. In developing countries, farmers usually sell their grain immediately after harvest to buy necessary consumer goods, repay their loans, insurance etc. Sometimes, they sell the wet grain immediately after harvest, even before harvest while the grain is still in the field. On the other hand, since the weather is not always bad throughout the harvesting season, farmers have opportunities to dry their harvested grain by sun and keep the grain with them. Farmers feel secure by having at least some portion of the harvested grain with them to meet their own consumption needs. Therefore, the assumption of selling the wet grain to the plant management is logically sound and realistic. In developing countries, farmers usually grow varieties of grain of the same type (i.e. different kinds of paddy) in the same season. It might create a problem of grain mixing during drying in the plant. Since the model has been developed for both batch and continuous (cross-flow) drying systems, the problem of mixing of different qualities or varieties of grain could be avoided by selecting an appropriate continuous type of drying system.

Because of the computing cost, searching for the optimum combination of the facilities sizes was performed for eight different weather sequences only. The analysis of the system with a fairly large number of weather sequences might lead to a better design. Since the precision of the system design and the computing cost are highly correlated, both factors must be considered simultaneously in designing the system. Only potential users of the model can decide what level of precision in designing a grain drying system would be acceptable. The another problem regarding the use of the model may be the availability of computer memory. Since the program requires a huge amount of computer memory, a further step may be taken to simplify the program so that it could be run by a microcomputer.

A search for the optimum combination of facility sizes was performed mainly by varying weather and drying capacity. After obtaining a potential optimum storage capacity (in this case 545.5 m^3) for a particular weather pattern (weather pattern 1), potential optimum storage capacity was kept constant until the optimum drying capacity was obtained (Table 5). Since storage capacity of the plant had a very insignificant effect on the NPVs of cash flow (Table 4), searching for the optimum combination of facility sizes was performed mainly with respect to weather and drying capacity. This practice has been followed due to limitation of time and money. However, appropriate design for experiment of the model should be followed while searching for the optimum combination of facility sizes for better design.

The market price of paddy was predicted using the past trend by the estimated regression equation shown in page 146. The equation indicates that in the past market price of paddy increased steadily. However, the future market price of paddy may decrease or increase or even remain the same depending on production, demand and supply. It is not an easy task to predict future prices of paddy correctly. Since market price of the grain had a very significant effect on the plant economy (Table 9), the use of a better price prediction model may increase the efficiency of the model.

The necessary instrument in the NPV criterion is the appropriate rate of interest or rate of discount by which the net cash flow at any point of time is weighted. An interest rate of 11% was used in this study, assuming that there is no variation of the rate with respect either to magnitude or time under a perfect capital market situations. The correct rate of interest should reflect society's rate of time preference. Since it is difficult to predict society's rate of time preference correctly, a single and constant rate of discount (11%) throught the simulated periods was utilized in this study to simplify the task.

It was gathered from a report of the Asian Development Bank (1982). Better results may be achieved using correct society's rate of time preference for each year of the simulated period. However, it may increase the cost of analysis.

Accuracy of the simulated grain drying system performance depends a great deal on the precision and adequacy of the input data. The model was applied as an example to design a paddy drying plant for a single location only. The B/C ratio for the application indicated that the investment to the drying plant may not be very attractive. However, in other cases (other locations), the model may produce better or worse results depending on input data and weather conditions of the localities. The efficiency of the model could be increased by adopting better grain harvesting and grain moisture content submodels. Introduction of a transportation cost submodel into the developed model might be appropriate when analysis of a grain drying system for a fairly large service area is needed. However, the model is so flexible that it could be easily performed by adding a subroutine into the program. Since the weather pattern in a locality may change after a certain period of time, input of longer periods of weather data may increase the performance of the model.

Not only the grain drying system, but also other important agricultural production and processing activities, such as design and operation of an irrigation system, pest control management, crop and land allocation etc. are largely dependent on weather. Thus, the developed model may be helpful to develop models of other weather dependent agricultural production and processing operations and may be applied for successful design, operation and management purposes.

REFERENCES

1 Agricultural Engineers Yearbook. 1982. American Society of Agricultural Engineers. St. Joseph, Michigan.

2 Asian Development Bank. 1982. Appraisal of the agro-processing and marketing project in the Republic of the Philippines. ADB. Manila, Philippines.

3 Baloco, T. C. 1980. Performance and cost analysis of different grain dryers at NFA complexes. Technical Research Division (TRSD), National Food Authority, Quezon City, Philippines.

4 Brooker, D. B., F. W. Bakker-Arkema and C. W. Hall. 1974. Drying cereal grains. The AVI Publishing Company, Inc. Westport, Connecticut.

5 Carpenter, M. L. and D. B. Brooker. 1972. Minimum cost machinery systems for harvesting, drying and storing shelled corn. TRANSACTIONS of the ASAE 15(3):515-519.

6 Chancellor, W. J. 1967. A simple grain dryer using conducted heat. ASAE paper no. 67-860. American Society of Agricultural Engineers. St. Joseph, Michigan.

7 Chang, D. I., D. S. Chung and T. O. Hodge. 1979. Grain drying selection model. ASAE paper no. 79-3519.

American Society of Agricultural Engineers. St. Joseph, Michigan.

8 Chen, Yi-Luen. 1974. A study on rice drying in Taiwan. Journal of Chinese Agricultural Engineering. Vol. 20, no. 3.

9 Chen, Yi-Luen. 1975. Alternative solution for rice emergency drying in rainy seasons. Journal of Chinese Agricultural Engineering. Vol. 21 no. 1.

10 Christensen, C. M. 1974. Storage of Cereal Grains and Their Products. American Association of Cereal Chemists. St. Paul, Minnesota.

11 FAO/UNDP. 1984. Drying and Handling of Wet Paddy. Proceedings of the FAO/UNDP regional workshop on rice post-harvest technology. RAS/81/046. 17-21 July 1984. Cabanatuan and Santiago, Philippines.

12 Fontana, C. 1983. Concurrent Flow Versus Conventional Drying of Rice. Ph.D. dissertation. Department of Agricultural Engineering. Michigan State University. University Microfilm International. 300 N. Zeeb Road, Ann Arbor, Michigan.

13 Gervacio, R. R. 1984. Philippine experience in the introduction of improved grain grading systems. In: Proceedings of the FAO/UNDP regional workshop on rice post-harvest technology. RAS/81/046. 17-21 July 1984. Cabanatuan and Santiago, Philippines.

14 Habito, C. and B. Duff. 1979. A simulation model to evaluate mechanization of rice post-harvest operations in the Philippines. In : the consequences of small rice farm mechanization project. Working paper no. 4. The International Rice Research Institute, Los Banos, Philippines.

15 Henderson, S. M. and S. Pabis. 1961. Grain drying theory I. Temperature effect on drying coefficient. Journal of Agricultural Engineering Research. U.K. 6(3):169-174.

16 Hukill, W. V. 1947. Basic principles of drying corn and grain sorghum. Agricultural Engineering. St. Joseph, Michigan. 28(8):335-338,340.

17 Hunt, D. 1979. Farm Power and Machinery Management. 7th ed. Iowa State University Press, Ames, Iowa.

18 IBM. 1983. FORTRAN IV Language. 12th edition. International Business Machines. San Jose, California.

19 Koh, H. K. and C. J. Chung. 1981. Solar and natural air drying of rough rice in Korea. In : Food drying. Proceedings of a workshop held at Edmonton, Alberta. International Development Research Centre, Ottawa, Canada. 6-9 July 1981.

20 Law, A. M. and S. G. Vincent. 1983. UNIFIT : An

interactive computer package for fitting probability distribution to observed data. Simulation Modeling and Analysis Company. P. O. Box 40996, Tocson, Arizona 85717.

21 Leung, P. 1977. A Generalized Animal Production System Design and Management Model. Ph.D. dissertation. Department of Agricultural and Resource Economics.University of Hawaii, Honolulu, Hawaii.

22 Loewer, O. J., T. C. Bridges and D. G. Overhults. 1976. Facility costs of centralized grain storage systems utilizing computer design. TRANSACTIONS of the ASAE 19(6):1163-68.

23 Lytle, P.W., T. L. Thompson and E. H. Rasschaert. 1974. Simulation and economic analysis of on-farm grain drying and storage systems. ASAE paper no. 74-3002. American Society of Agricultural Engineers, St. Joseph, Michigan.

24 Manilay, A. A. and J. J. Lorenzana. 1984. A feasibility study of a thresher-drier-mill operation at the farmers' association level. In : Proceedings of the FAO/UNDP regional workshop on rice post-harvest technology. 17-22 July, 1984. Cabanatuan and Santiago, Philippines.

25 Moss, C. J. 1965. Future world needs of mechanical

power in agriculture. An address to the British Association for Advancement of Science, Section M. Cambridge, U.K.

26 Padua, D. B., A. A. Mainlay and A. S. Frio. 1984. Coming to grips with the wet season grain handling problems in Southeast Asia. In: Proceedings of the FAO/UNDP regional workshop on rice post-harvest technology. RAS/81/046. 17-21 July 1984. Cabanatuan and Santiago, Philippines.

27 Price, C. 1964. The Relationship Between Costs, Output and Capacity for Rice Drying Facilities in Louisiana and Texas. Ph.D. dissertation. Department of Agricultural Economics and Agribusiness. Louisiana State University. Louisiana.

28 Seedburo Equipment Company. 1982. Price Catalog(motors and electrical safety devices). Seedburo Equipment Company. 1022 West Jackson Boulevard, Chicago, Illinois 60607.

29 Turner, M. S. and G. B. Baker. 1976. Grain drying in country elevators, costs and economics of size. Special bulletin. Nebraska Agricultural Experimental Station. No. SB 537. 38 pp. Department of Agricultural Economics. University of Nebraska, Lincoln, U.S.A.

30 Vega, C. G. 1984. The integrated growth and development of the food industry : Philippines experience on post-harvest technology. In : Proceedings of the FAO/UNDP Regional Workshop on Rice Post-harvest Technology. 17-22 July, 1984. Cabanatuan and Santiago, Philippines.

31 Wimberly, J. M. and F. E. Sistler. 1982. Computer selection of commercial scale rice drying components. ASAE paper no. 82-3517. American Society of Agricultural Engineers. St. Joseph, Michigan.

32 Woody, E. R. and W. R. Morrison. 1979. Costs of owning and operating on-farm drying-storage facilities for rice : A case study. Agricultural Experiment Station. report no. 84.University of Arkansas, Fayetteville, U.S.A.

33 Yon, R. M. and D. M. Nour. 1984. Malaysian approach toward the handling of wet padi. In: Proceedings of the FAO/UNDP regional workshop on rice post-harvest technology. 17-21 July, 1984. Cabanatuan and Santiago, Philippines.

34 Young, J. H. and J. W. Dickens. 1975. Evaluation of costs for drying grain in batch or cross-flow systems. TRANSACTIONS of the ASAE. St. Joseph, Michigan 18(4):734-739.

APPENDIX A

GRAIN DRYING MODELS USED IN THE SPGDM PROGRAM

1. Energy Cost of Grain Drying : Energy cost of grain drying is directly proportional to temperature rise of drying air above ambient, air flow rate, drying time and the cost of energy. It is calculated by the following model developed by Young and Dickens (1975, p.735) and is suitable for batch and cross-flow continuous dryers.

$$C_d = \frac{(T_h - T_a)\ m\ (\ C_{pa} + H_r\ C_{pv}\ )\ P_1}{q_1\ e_0\ (\ A_a\ X\ /\ t_d\ )} \quad \ldots\ldots\ldots(1)$$

$$\text{or,} \quad C_d = \frac{(T_h - T_a)\ m\ (\ C_{pa} + H_r\ C_{pv}\ )\ P_1}{q_1\ e_0\ D_r} \quad \ldots\ldots\ldots(2)$$

where,

A_a = Cross-sectional area of dryer, m^2

C_d = Energy cost of grain drying, M/m^3 of grain

C_{pa} = Specific heat of dry air, kJ/kg^0C

C_{pv} = Specific heat of water vapor, kJ/kg^{0}C

D_r = Drying capacity of the dryer, m^3/t_d hr

e_0 = Overall thermal efficiency of the dryer, decimal

H_r = Humidity ratio of ambient air, kg of H_2O/kg of air

M = Any monetary unit

m = Mass flow rate of drying air (heated), kg/hr

P_1 = Price of energy for grain drying, M/unit

q_1 = Heat content of energy for grain drying, kJ/unit

T_a = Ambient air temperature, ^{0}C

T_h = Drying (heated) air temperature, ^{0}C

t_d = Time of drying (duration of one shift, example 8 hours), hr

X = Depth of grain in the drying bin, m

Equation 2 calculates cost of grain drying for a time period of t_d hours. For a selected value of M_a, values of m and H_r are determined from equation 3 and equation 12 respectively. The mass flow rate, m is calculated from equation 3 as suggested by Young and Dickens (1975).

$$m = \frac{D_r \, \rho \, Lv \; (M_0 - Me)}{100 \; C_{pa} \; D_d \; H \; (Th - Te) \; / \; t_d} \quad \ldots\ldots\ldots\ldots\ldots(3)$$

where,

$$D_d = \frac{\mathrm{Ln}\ [\ ((2^{D_d}) - 1)\ \exp\ (-(t_d\ \mathrm{Ln}\ 2)/H) + 1\ ]}{M_r\ \mathrm{Ln}\ 2} \quad \ldots(4)$$

and

$$M_r = \frac{M_a - M_e}{M_0 - M_e} \quad \ldots\ldots(5)$$

where,

D_d = Number of dimensionless depth units to the point where M_a is calculated

H = Time-of-half-response of the grain being dried, hr

L_v = Latent heat of vaporization of moisture in the grain, kJ/kg

M_a = Average grain moisture content (after drying), % db

M_e = Equilibrium moisture content of the grain for initial condition of the air entering the grain, % db

M_0 = Initial moisture content of the grain, % db

M_r = Moisture ratio

T_e = Equilibrium temperature; temperature at which air would be in equilibrium with the grain at its initial moisture content after the air has cooled adiabatically, ^0C

ρ = Density of grain dry matter, kg/m^3

L_v, Q, H, M_e and T_e are calculated from equation 6, 7, 8, 10 and 11 respectively. The latent heat of vaporization of grain moisture may be calculated from equation 6 (Fontana, 1983, p.31).

$$L_v = b_2 (1090 - b_3 (T_g + c_2))(1 + b_4 \exp (-c_3 M_a)) \quad ..(6)$$

where,

T_g = Grain temperature, ^0C

b_2, b_3, b_4 = Constants for a particular grain

c_2, c_3 = Constants for a particular grain

The air flow rate of drying air(heated) is;

$$Q = \frac{m\ v_s}{3600\ A_a} \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

where,

$$v_s = \frac{287 \; (T_h + 273.16)}{(P_a - P_v)}$$ (Agricultural Engineers Yearbook, 1982, p.332)

and

$$P_v = R_h * P_{sh}$$ (Agricultural Engineers Yearbook, 1982, p.332)

where,

P_a = Atmospheric pressure, Pa

P_{sh} = Saturated vapor pressure at T_h, Pa

P_v = Vapor pressure, Pa

Q = Air flow rate through grain, $m3/m2-s$

R_h = Relative humidity of drying air (heated), decimal

v_s = Specific volume of drying air (heated) at T_h, m^3/kg

Saturated vapor pressure (P_{sh}) at T_h is calculated from equation 13. Relative humidity of drying (heated) air, R_h may be obtained from equation 14. Time-of-half-response has been calculated from equation 8 (Young and Dickens, 1975, p.1).

$$H = \frac{\text{Ln } 2}{K_d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

where,

K_d = Thin layer drying constant, hr^{-1}

Henderson and Pabis (1961) developed a model to determine drying constant of grain. The same has been used here,

$$K_d = b_1 \exp \left(c_1/(T_h + 273.16)\right) \quad \ldots\ldots\ldots\ldots (9)$$

where,

b_1 = A constant for a particular grain

c_1 = A constant for a particular grain

The equilibrium moisture content (Agricultural Engineers Yearbook, 1982, p.318) is;

$$M_e = \left[\frac{\text{Ln } (1 - R)}{- c\,(T + b)}\right]^{1/n} \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

where,

b, c, n = Constants for a particular grain

R = Relative humidity of air, decimal

The equilibrium temperature is determined by using equation 11 with the assumption that the exhaust air relative humidity, $R_e = 0.85$ (Hukill, 1947 p.338)

$$T_e = -\left[b + \frac{\mathrm{Ln}\,(1 - R_e)}{c\, M_0{}^{n}} \right] \quad \text{.........(11)}$$

where,

R_e = Relative humidity of exhaust air, decimal

Humidity ratio (Agricultural Engineers Yearbook, 1982, p.332) is;

$$H_r = \frac{0.621\, R_a\, P_{sa}}{(P_a - R_a\, P_{sa})} \quad \text{..............(12)}$$

where,

P_{sa} = Saturated vapor pressure at T_a, Pa

R_a = Relative humidity of ambient air, decimal

The saturated vapor pressure, P_s at temperature T (Agricultural Engineers Yearbook, 1982, p.331) is;

$$P_s = \exp((\text{Numerator}/\text{Denominator}) + 16.91) \quad \ldots(13)$$

where,

$$\begin{aligned} \text{Numerator} &= -27405.526 + 97.5413(T + 273.16) - 0.146244(T \\ &\quad + 273.16)^2 + 0.12558 * 10^{-3}(T + 273.16)^3 \\ &\quad - 0.48502 * 10^{-7}(T + 273.16)^4 \\ \text{Denominator} &= 4.34903(T + 273.16) - 0.39381(T + 273.16)^2 * \\ &\quad 10^{-2} \end{aligned}$$

Equation 13 is used to determine P_{sa} and P_{sh} at their respective temperatures. The relative humidity of drying (heated) air (Agricultural Engineers Yearbook, 1982, p.332) is;

$$R_h = \frac{H_r\ P_a}{(H_r + 0.6219)\ P_{sh}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(14)$$

2. Cost of Grain Drying by Solar Radiation (Natural Thin Layer Drying

Cost of grain drying (labor cost) using solar radiation may be calculated as follows;

$$C_{ds} = (A1 / A2) P3 D_{sh} \quad \ldots\ldots\ldots\ldots\ldots(15)$$

where,

A_1 = Surface area for sundrying, m^2

A_2 = Surface area (for sundrying) that can be managed effectively by a single laborer, m^2

C_{ds} = Cost of grain drying by sun, M/day

D_{sh} = Daily available solar hours, hr/day

P_3 = Labor price, M/hr

The moisture content of grain after one day of sundrying is (Henderson and Pabis, 1961);

$$M_s = M_e + (M_a - M_e) \exp (-K_d D_{sh}) \ldots(16)$$

where,

M_s = Moisture content of the grain after a day of sundrying, % db

3. Cost of Fan Operation for Moving Air Through Grain During Drying

$$C_{of} = C_{fo} D_r W_r \quad \text{.......................(17)}$$

where,

$$C_{fo} = \frac{P_f t_d P_2}{e_1} \quad \text{...............(18)}$$

where,

C_{fo} = Cost of fan operation, M/m^3

C_{of} = Cost of fan operation, M/day

e_1 = Overall efficiency of fan-motor or fan-engine system, decimal

P_f = Power required to force air through grain, kW/m^3

P_2 = Price of energy/electricity, M/unit

W_r = Number of shifts (a shift of t_d hrs.) of plant operation per day

Power required to force air through grain may be calculated from equation 19.

$$P_f = \frac{Q\ D_p}{1000} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

where,

D_p = Pressure drop through grain per unit depth of grain, Pa/m

D_p is calculated from the following relationship (Agricultural Engineers Yearbook, 1982, p.319).

$$D_p = q\ Q^y \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

where,

y = A constant

q = A constant

4. Cost of Elevating/Conveying Grain During Drying

The cost of elevating or conveying grain is;

$$C_{ec} = \frac{P_e\ t_d\ P_2\ W_r}{e_2} \quad \ldots\ldots\ldots\ldots (21)$$

where,

C_{ec} = Cost of elevating/conveying the grain, M/day

e_2 = Overall efficiency of grain conveyor or elevator, decimal

P_e = Power required to elevate/convey the grain, kW

P_e is calculated from equation 22.

$$P_e = \frac{D_r \rho_w l_m x_6}{367085} \quad \ldots\ldots\ldots\ldots\ldots(22)$$

where,

l_m = Height of storage bin, m

x_6 = Height increment factor for grain elevator, (> 1)

ρ_w = Density of wet grain at harvest, kg/m^3

APPENDIX B

THE GRAIN HARVESTING MODEL

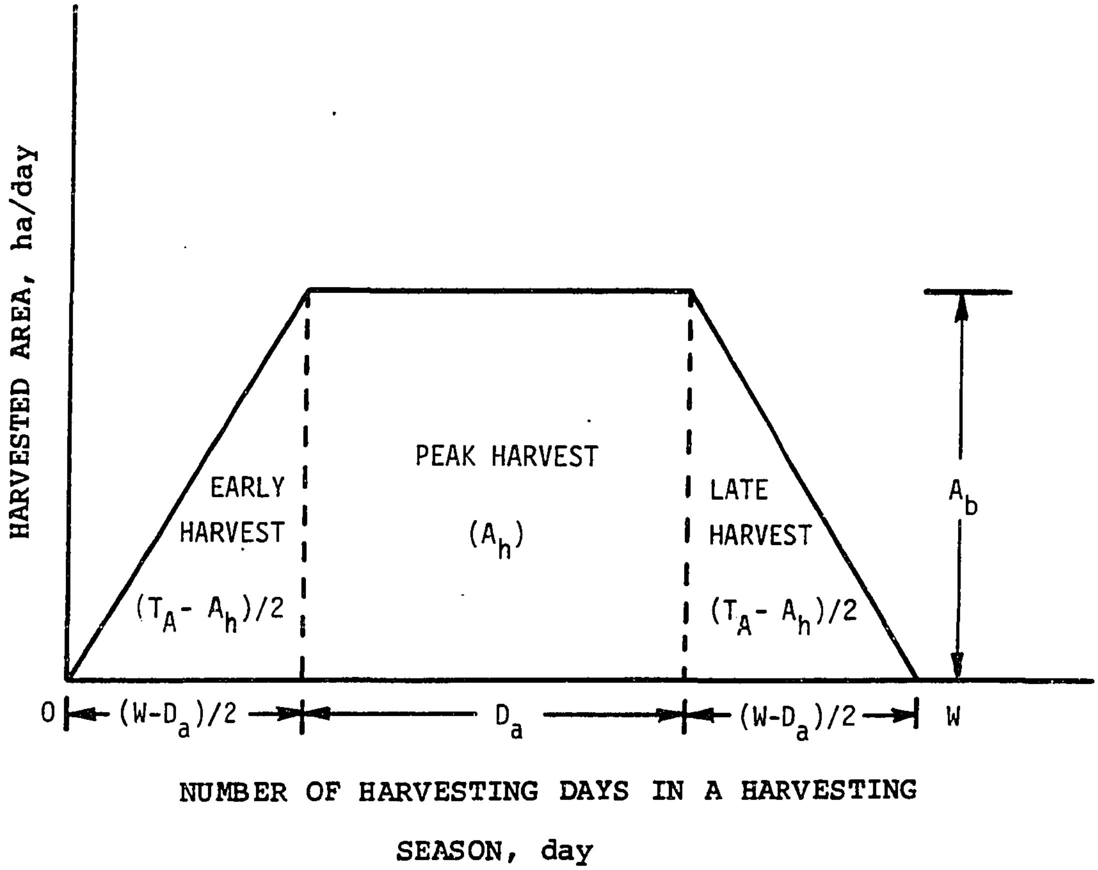


Figure 19 A Hypothetical Pattern of Daily Grain Harvest in a Harvesting Season

The program SPGDM calculates the total number of harvesting days during peak harvest (D_a), the total number of harvesting days in a harvesting season (W) and the total area to be harvested during the period of peak harvest (A_h). In each harvesting season, W is calculated logically by the program itself. The following relationships have been use by this harvesting model.

$$D_a = x . W \qquad \text{..........................(23)}$$

where,

x = Mean percentage of total harvesting days during peak harvest, decimal. This may be gathered from farmers' interview, if no secondary information is available.

Total number of harvesting days in an early or a late harvest period (W_{el}) in a harvesting season is;

$$W_{el} = \frac{(W - D_a)}{2} \qquad \text{..........................(24)}$$

The total area to be harvested during peak harvest (A_h) is;

$$A_h = z\ T_A \qquad \text{..........................(25)}$$

where,

T_A = Mean total crop area within the service area of the plant, ha

z = Mean percentage of total area to be harvested during peak harvest, decimal. This information may be gathered from farmers' interview, if no secondary information is available.

The total area to be harvested in an early or a late harvest period (A_{el}) in a harvesting season is;

$$A_{el} = \frac{(T_A - A_h)}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(26)$$

The daily area harvested during peak harvest (A_b) is;

$$A_b = \frac{A_h}{D_a} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(27)$$

The daily area harvested during the early harvest (A_e) is;

$$A_e = \frac{A_b}{W_{el}} D_n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (28)$$

where,

D_n = Working days in an early harvest period, days

The daily area harvested in a late harvest (A_t) is;

$$A_t = \frac{A_b}{W_{el}} D_m \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (29)$$

where,

D_m = Working days in a late harvest period, days.

APPENDIX C

MODELS USED IN THE SPFA PROGRAM FOR FINANCIAL ANALYSIS

1. Capital consumption

The capital consumption (i.e. depreciation plus interest on salvage value) on facilities and equipment is calculated as follows (Hunt, 1979, p.67);

$$C_c = (P - S)\, C_{rf} + S\, r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (30)$$

where,

$$C_{rf} = \frac{r\,(1 + r)^L}{(1 + r)^L - 1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (31)$$

where,

C_c = Capital consumption on facilities and equipment, M/yr

C_{rf} = Capital recovery factor

L = Life of equipment and facilities, yr

P = Purchase price of equipment/ facility and is a function of capacity or size of that equipment/ facility, M

r = Interest rate, decimal

S = Salvage value of equipment or facility at the end of Lth year, M

2. Sales and Property Taxes

i) Sales tax (Hunt, 1979, p 68)

$$T_{st} = \frac{P\ x_2}{L} \quad \text{.........................}(32)$$

where,

T_{st} = Sales tax, M/yr

x_2 = Sales tax rate, decimal

ii) Property tax (Hunt, 1979, p 68)

$$T_p = \frac{0.5\ P\ x_3}{2} \quad \text{......................}(33)$$

where,

T_p = Property tax, M/yr

x_3 = Property tax rate, decimal

3. Insurance Cost (Hunt, 1979, p 68)

$$I_p = P\ x_4 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (34)$$

where,

I_p = Insurance payment, M/yr

x_4 = Insurance rate, decimal

4. Shelter Cost (Hunt, 1979, p 68)

$$C_{st} = P\ x_5 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (35)$$

where,

C_{st} = Shelter cost, M/yr

x_5 = Shelter cost rate, decimal

5. The Total Fixed Cost

$$C_F = (C_c + T_{st} + T_p + I_p + C_{st}) \ldots\ldots\ldots (36)$$

where,

C_F = Total fixed cost of the entire plant, M/yr

6. Value of Land at the End of Nth Year

The value of land at the end of the Nth year is calculated as follows, assuming no depreciation or appreciation of land value. However, in some cases the future value of land may appreciate (example; a future development scheme for the area such as an irrigation project) or depreciate (example; a government plan to establish a nuclear power plant nearby). Although the equation 37 may not be necessary under the assumption of no depreciation or appreciation of land value (see the equation in page 31), it is incorporated into the program only with a view to easy modification of the program by replacing the equation with an appropriate one, in a case where the assumption is no longer valid.

$$VL = LAN * (1 + r)^N \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (37)$$

APPENDIX D

FITTED PROBABILITY DISTRIBUTIONS TO DAILY AIR TEMPERATURE IN LOS BANOS, PHILIPPINES FROM 1959-1983

Density $f(x) = \dfrac{(1/\beta)\exp[-(x-\gamma)/\beta]}{(1+\exp[-(x-\gamma)/\beta])^2}$ for $-\infty < x < \infty$

Distribution $F(x) = (1+\exp[-(x-\gamma)/\beta])^{-1}$ for $-\infty < x < \infty$

Parameters Location parameter $\gamma \in (-\infty, \infty)$, scale parameter $\beta > 0$

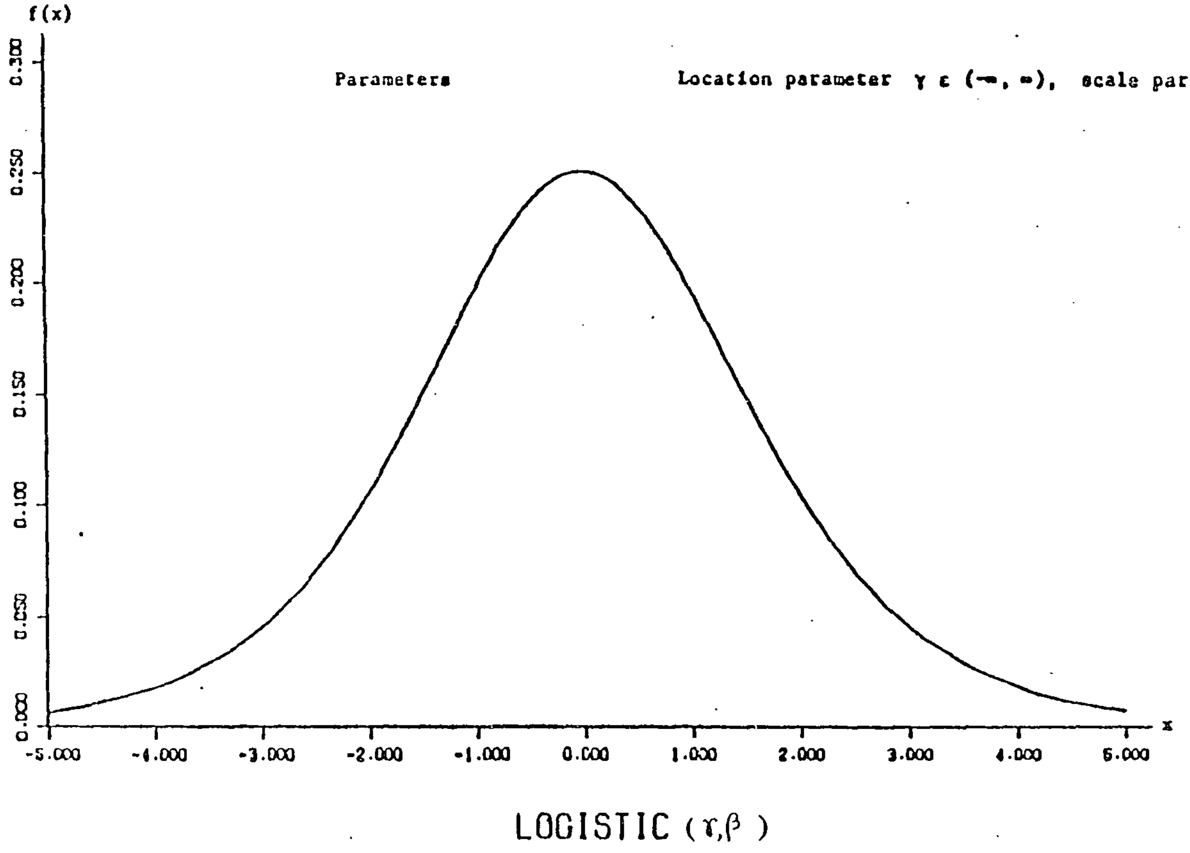
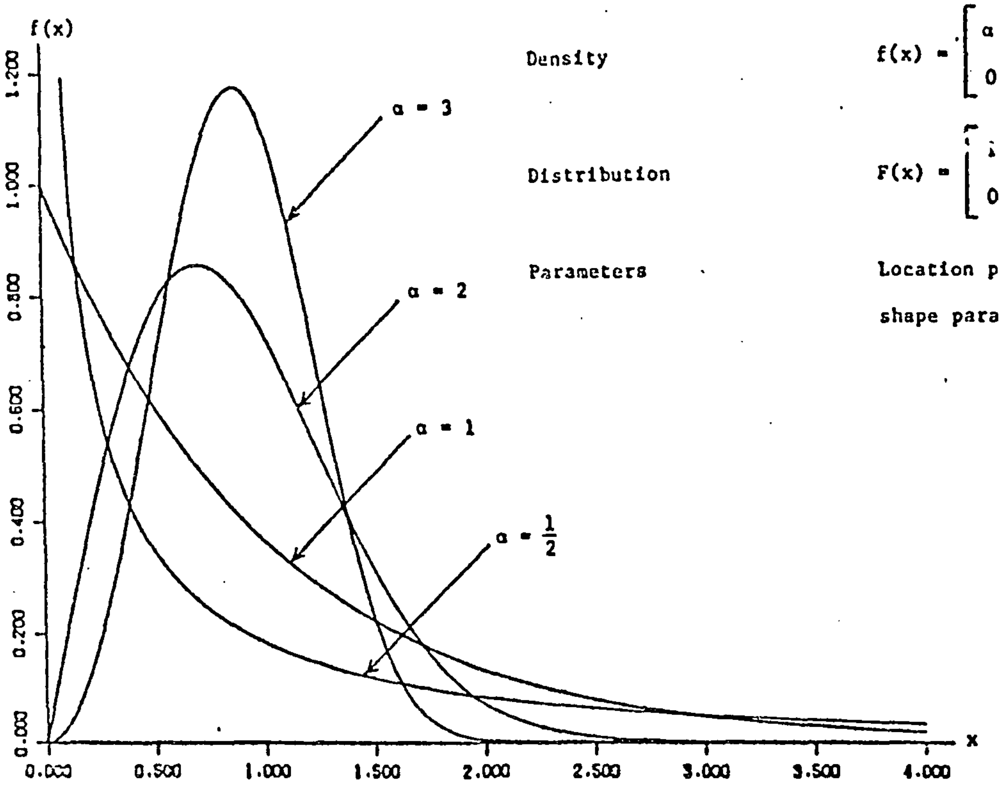


Figure 20 Logistic (0,1) Density Function



Density

$$f(x) = \begin{cases} \alpha \beta^{-\alpha}(x-\gamma)^{\alpha-1} \exp(-[(x-\gamma)/\beta]^{\alpha}) & \text{if } x > \gamma \\ 0 & \text{otherwise} \end{cases}$$

Distribution

$$F(x) = \begin{cases} 1 - \exp(-[(x-\gamma)/\beta]^{\alpha}) & \text{if } x > \gamma \\ 0 & \text{otherwise} \end{cases}$$

Parameters

Location parameter $\gamma \in (-\infty, \infty)$, scale parameter $\beta > 0$, shape parameter $\alpha > 0$

WEIBULL(γ,β,α)

Figure 21 Weibull (0,1,α) Density Function

Density	$f(x) = (1/\sqrt{2\pi\beta^2}) \exp[-(x - \gamma)^2/2\beta^2]$ for $-\infty < x < \infty$
Distribution	No closed form
Parameters	Location parameter $\gamma \in (-\infty, \infty)$, scale parameter $\beta > 0$

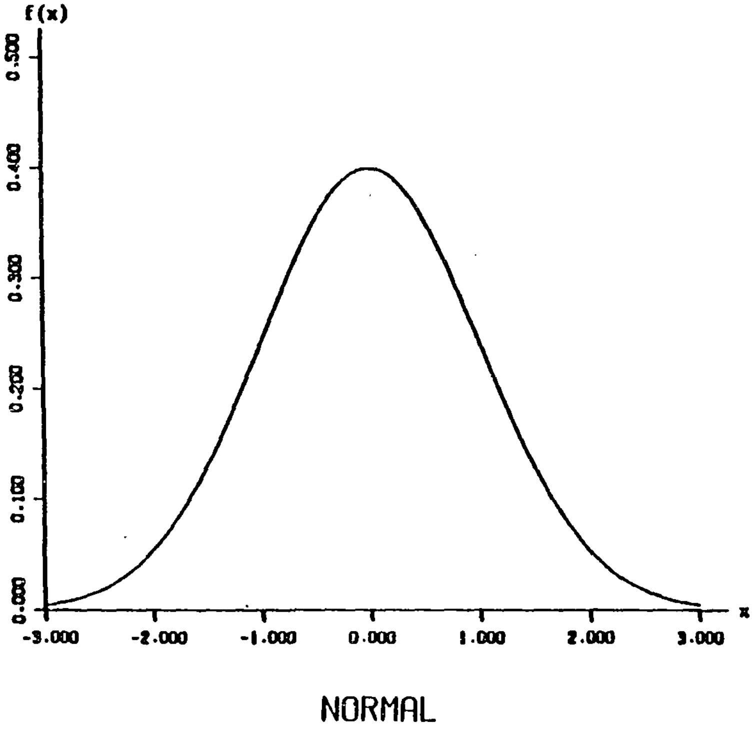


Figure 22 Normal (0,1) Density Function

Density	$f(x) = (1/\beta)\exp[(x-\gamma)/\beta]\exp\{-\exp[(x-\gamma)/\beta]\}$ for $-\infty < x < \infty$
Distribution	$F(x) = 1 - \exp\{-\exp[(x-\gamma)/\beta]\}$ for $-\infty < x < \infty$
Parameters	Location parameter $\gamma \in (-\infty, \infty)$, scale parameter $\beta > 0$

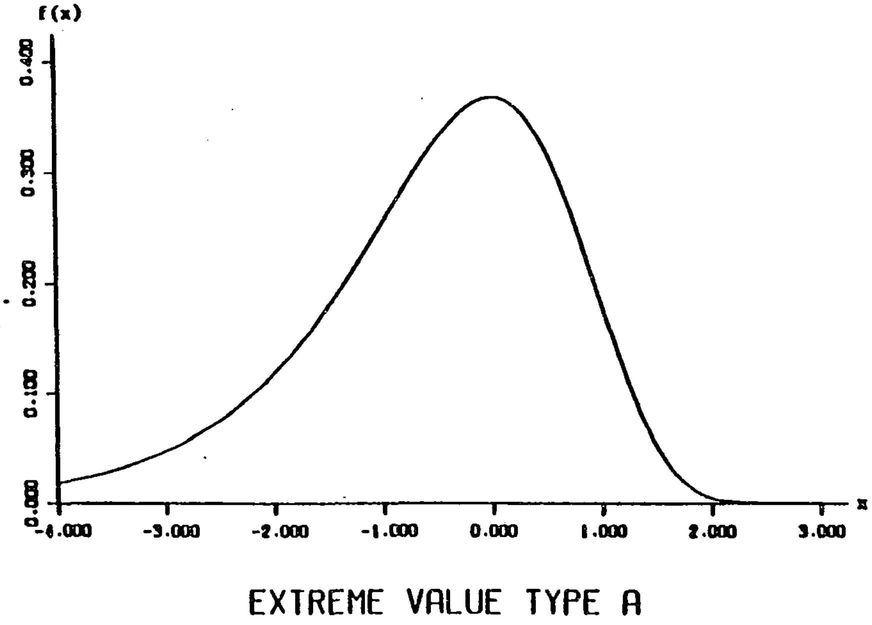


Figure 23 Extreme Value Type A (0,1) Density Function

APPENDIX E

DEFINITION OF WEATHER PATTERNS AS GENERATED BY USING BASIC UNIFORM (0,1) RANDOM NUMBER GENERATOR (GGUBFS)

Weather Pattern	Percent of no sunny days during harvesting seasons of entire simulated period	Total no. of sequence of no sun today and no sun tomorrow during harvesting seasons of entire simulated period	Maximum no. of successive no sunny days during harvesting seasons of entire simulated period	DSEED as used in the random number generator (GGUBFS)
1	39.57	240	8	123457.D0
2	41.44	251	9	254786.D0
3	41.21	255	9	119329.D0
4	41.74	255	9	1216924.D0
5	40.30	256	10	60768.D0
6	43.18	276	11	249377.D0
7	41.82	276	12	11921.D0
8	41.82	285	15	80051.D0

APPENDIX F

THE MOISTURE CONTENT (WET BASIS) OF PADDY VERSUS DAYS FROM MATURITY AT HARVEST

Days from maturity	Moisture content, %	Harvest loss, %	Variety[a]	Author
-12	24.7-25.7	0.307	BG 34-8	Sarath (1978)
-12	25.8-26.0	0.105	BG 94-1	Sarath (1978)
-8	16.8-24.9	0.328	BG 34-8	Sarath (1978)
-8	21.6-25.4	0.227	BG 94-1	Sarath (1978)
-7	23.9-25.8	0.513	BPI-121	Ruiz and Castelo (1965)
-7	23.9-25.8	0.920	BPI-121	Ruiz and Castelo (1965)
-7	23.9-25.8	1.498	BPI-121	Ruiz and Castelo (1965)
-7	23.9-25.8	0.401	BPI-121	Ruiz and Castelo (1965)
-7	NA	0.40	Bahagia	Horiuchi et al. (1971)
-6	23.4	0.45	IR-20	Samson and Duff (1973)
-6	23.7	0.40	IR-20	Samson and Duff (1973)
-5	22.4	1.00	IR-20	Samson and Duff (1973)
-5	23.1	0.79	IR-24	Samson and Duff (1973)
-5	23.0	1.64	C4-63	Samson and Duff (1973
-5	23.2	2.47	IR-253	Samson and Duff (1973)
-4	NA	1.87	Bahagia	Horiuchi et al. (1971)
-4	NA	1.98	Bahagia	Horiuchi et al. (1971)
-4	NA	1.17	Bahagia	Horiuchi et al. (1971)
-4	16.2-25.2	0.521	BG 34-8	Sarath (1978)
-4	19.8-21.8	0.333	BG 94-1	Sarath (1978)
-4	31.4-34.8	1.71	IR-8	Cristal and Ravalo (1967)
0	20.8	0.80	IR-20	Samson and Duff (1973)
0	19.5	0.97	IR-20	Samson and Duff (1973)
0	20.0	1.43	IR-20	Samson and Duff (1973)
0	20.1	1.27	IR-24	Samson and Duff (1973)
0	20.6	2.17	C4-63	Samson and Duff (1973)
0	20.5	3.03	IR-253	Samson and Duff (1973
0	20.8-22.8	3.575	BPI-121	Ruiz and Castelo (1965)
0	20.8-22.8	3.001	BPI-121	Ruiz and Castelo (1965)
0	20.8-22.8	3.237	BPI-121	Ruiz and Castelo (1965)
0	20.6-22.8	3.635	BPI-121	Ruiz and Castelo (1965)
0	26.0-30.5	3.40	IR-8	Cristal and Ravalo (1967)
0	NA	0.57	Bahagia	Horiuchi et al. (1971)
0	14.2-18.5	0.503	BG 34-8	Sarath (1978)
0	18.6-21.1	0.445	BG 94-1	Sarath (1978)
+4	21.2-23.6	6.16	IR-8	Cristal and Ravalo (1967)
+4	13.5-16.0	0.867	BG 34-8	Sarath (1978)
+4	16.8-20.6	0.525	BG 94-1	Sarath (1978)
+5	16.6	2.06	IR-20	Samson and Duff (1973)
+5	18.2	1.73	IR-24	Samson and Duff (1973)
+5	16.6	2.10	C4-63	Samson and Duff (1973)
+5	18.7	2.19	IR-253	Samson and Duff (1973)
+6	18.0	1.30	IR-20	Samson and Duff (1973)
+6	16.8	1.65	IR-20	Samson and Duff (1973)
+7	19.1-19.9	8.356	BPI-121	Ruiz and Castelo (1965)
+7	19.1-19.9	3.917	BPI-121	Ruiz and Castelo (1965)
+7	19.1-19.9	7.037	BPI-121	Ruiz and Castelo (1965)
+7	17.1-19.1	3.781	BPI-121	Ruiz and Castelo (1965)
+8	13.8-18.1	0.952	BG 34-8	Sarath (1978)
+8	16.5-18.8	0.834	BG 94-1	Sarath (1978)
+10	15.3	2.08	IR-20	Samson and Duff (1973)
+10	15.6	2.00	IR-24	Samson and Duff (1973)
+10	15.4	2.68	C4-63	Samson and Duff (1973)
+10	16.3	4.06	IR-253	Samson and Duff (1973)
+12	16.2-17.2	16.30	IR-8	Cristal and Ravalo (1967)
+12	15.3-26.9	1.443	BG34-8	Sarath (1978)
+14	16.9-17.7	3.797	BPI-121	Ruiz and Castelo (1965)
+14	16.9-17.7	9.959	BPI-121	Ruiz and Castelo (1965)
+14	16.9-17.7	7.287	BPI-121	Ruiz and Castelo (1965)
+14	16.9-17.7	12.721	BPI-121	Ruiz and Castelo (1965)
+21	15.5-15.7	51.253	BPI-121	Ruiz and Castelo (1965)
+21	15.5-15.7	54.062	BPI-121	Ruiz and Castelo (1965)
+21	15.5-15.7	30.705	BPI-121	Ruiz and Castelo (1965)
+21	15.5-15.7	27.957	BPI-121	Ruiz and Castelo (1965)
+21	15.5-15.7	27.657	BPI-121	Ruiz and Castelo (1965)
+21	NA	3.08	Bahagia	Horiuchi et al. (1971)
+21	NA	3.61	Bahagia	Horiuchi et al. (1971)
+21	NA	2.53	Bahagia	Horiuchi et al. (1971)
+28	13.3-13.6	65.364	BPI-121	Ruiz and Castelo (1965)
+28	13.3-13.6	56.051	BPI-121	Ruiz and Castelo (1965)
+28	13.3-13.6	54.042	BPI-121	Ruiz and Castelo (1965)
+28	13.3-13.6	66.192	BPI-121	Ruiz and Castelo (1965)

[a] BG 34-8, BG 94-1, Bahagia, IR-20, and IR-24 are classified as low-shattering; C4-63 and IR-253 are classified as medium-shattering; and BPI-121 and IR-8 are classified as high-shattering varieties.

Source: Habito and Duff (1979)

APPENDIX G

EQUIVALENT NET WEIGHT FACTOR FOR PALAY (PADDY)

%MC % PURITY	14%	14-1-14.5%	14.6 15%	15.1-15.5%	15.6-16%	16.1-17%	17.1-18%	18.1-19%	19.1-20%	20.1-21%	21.1-22%	22.1-23%	23.1-24%	24.1-25%	25.1-26%
95 – 100%	1.00	.97	.96	.95	.94	.92	.90	.88	.86	.85	.83	.81	.80	.78	.77
90 – 94.9%	.97	.95	.94	.93	.92	.90	.88	.86	.84	.82	.81	.79	.77	.76	.74
85 – 89.9%	.92	.89	.88	.87	.86	.85	.83	.81	.79	.77	.76	.74	.73	.71	.70

INSTRUCTIONS FOR THE USE OF THE TABLE:

1) Determine the Gross Weight (GW) of the palay.
2) Determine the Net Weight (NW) of the palay by subtracting the weight of container from the Gross Weight.
3) Determining the % Moisture Content and the % Purity of the palay.
4) Based on the % Moisture Content and the % Purity determine the Equivalent Net Weight Factor (ENWF).
5) Multiply the Net Weight to the weight factor to get the equivalent Net Weight
6) Peso Value: Equivalent Net Weight x buying price.

N.B. This table shall not be used for liquidation or other purposes except for palay procurement only.

Quality Standards for Palay: 14% MC and 95% Purity

Source: Gravacio (1984)

APPENDIX H

SOURCES OF DATA

The data used in the model was collected from several institutions in the Philippines. Most of the data was obtained from secondary sources, only a few were gathered from farmers interviews. The grain paddy and the Los Banos area of the Philippines were chosen for development and verification of the model. The Agricultural Engineering Department and the Multiple Cropping Department of the International Rice Research Institute (IRRI), Philippines Council for Agriculture and Resources Research (PCARR), National Food Authority (NFA), Asian Development Bank (ADB), Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA), the Los Banos Municipal Office and local machinery manufacturers and dealers were the main sources of data.

The daily weather data from 1959 to 1983 at Los Banos, Laguna Province of the Philippines was obtained from the Multiple Cropping Department of IRRI; yield and price information of paddy and wage rate from PCARR; technical and cost information on dryers and their acessories from the

Agricultural Engineering Department of IRRI, the NFA, and agricultural machinery manufacturers and dealers. The interest rate, tax information, cost of storage structure and cost of energy for the dryer were obtained from ADB and SEARCA. The cost and rent information on agricultural land and harvesting information were collected from the Los Banos Municipal Office and local farmers. The year 1982, was considered as a base year for necessary computation in verification and testing the model.

APPENDIX I

SUMMARY OF INPUT DATA FOR GRAIN DRYING SYSTEM ANALYSIS

A. Weather Data

The daily weather data in Los Banos, Philippines, from 1959-1983 has been utilized in this study. The daily input weather elements are; Year (IYR)*, Month (MON), Day (IDAY), Minimum air temperature (TEMN), Maximum air temperature (TEMX), Mean relative humidity of air (HUM), Rainfall (RAIN), Solar radiation (SOLAR) and Wind speed (WIND).

B. Other Processed Data

1. Surface area for sundrying of grain, m^2 (A1)* = 2250.0
2. Cross-sectional area of storage for wet grain, m^2 (A3) = 25.0

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* Symbols inside the parentheses used in this section only refer to the input variable name used in the computer program in Appendix L.

3. Cross-sectional area of storage for dry grain, m^2 (A4) = 50.0

4. Area harvested (service area of the plant), ha (ACH) = 500.0

5. Annual increase of pay/salary, decimal (AIP) = 0.05

6. Moisture content of partially dried grain, dried by the plant, % db (AMO) = 20.0

7. Maximum income limit where corporate income tax changes, Peso (BRK) = 100000.0

8. Critical level of solar radiation for determination of sun-no sun day, cal/cm^2/day (C1) = 250.0

9. Critical level of solar radiation for determination of harvest-no harvest day, cal/cm^2/day (C2) = 110.0

10. Critical level of wind speed for determination of wind-no wind day for grain harvest, km/hr (C3) = 15.0

11. Capacity bracket of elevator, needed during purchase, m^3/hr (CBL) = 10.6

12. Corporate income tax for 1st bracket, decimal (CTAX1) = 0.25

13. Corporate income tax for 2nd bracket, decimal (CTAX2) = 0.35

14. Density of dry grain at M_f % db, kg/m^3 (DDG) = 572.26
15. Drying capacity of the plant, m^3/t_d hrs. (DR) = 37.00
16. Storage capacity for dry grain, m^3 (DSC) = 579.00
17. Initial value used for random number generation process, (DSEED) = 60768.D0
18. Mean density of harvested wet grain, kg/m^3 (DWG) = 642.54
19. Height or length bracket of the elevator or conveyor, needed during purchase, m (ELL) = 3.05
20. Height increment factor for grain elevator, (FE) = 1.10
21. Extra land that might be needed for road, loading/unloading and miscellaneous use, m^2 (FL) = 500.0
22. Final safe moisture level of paddy, % db (FM) = 14.0
23. Minimum moisture content of paddy at harvest, % db (GIM) = 26.0
24. Maximum moisture content of paddy at harvest, % db (GXM) = 30.0
25. Grain handling and quality losses during entire processing operation, decimal (HQL) = 0.005
26. Beginning year of the input weather data

minus one, (IFY) = 58

27. First day of Ist harvesting season, (IF1) = 232

28. First day of 2nd harvesting season, (IF2) = 311

29. Last day of Ist harvesting season, (IL1) = 274

30. Last day of 2nd harvesting season, (IL2) = 355

31. Number of future bad days that farmers may wait for sundrying before they decide to sell their grain to the plant management, (KFD) = 1

32. An indicator for drying of partially dried grain, (KSD). KSD = 1 means partially dried grain is dried by the plant. If plant is not available, it is dried finally by sun. KSD = 2 means partially dried grain is dried by natural sun. If sun is not available, it is dried finally by the plant. = 1

33. An indicator for dry grain sale to the market, (KSY). KSY = 1 means all dry grain is sold out at the end of each drying season. KSY = 2 means all dry grain is sold out only at the end of each year = 1

34. A decision indicator for use of weather data, (KWD). KWD = 1 means historical weather data is used directly. KWD = 2 means historical weather data is used to

generate daily temperature and relative humidity of air, using fitted probability distribution. = 1

35. End of year of input weather data plus one, (LY) = 84

36. Time span between two successive years of change grain production, year (M1) = 10

37. Time span between two successive years of price change of electricity, year (M2) = 2

38. Time span between two successive years of price change of fuel (kerosene) for grain drying, (M3) = 2

39. Total number of historical years used in input weather data, (N) = 25

40. Number of paddy harvesting season in a year, (NOS) = 2

41. Number of simulated year, that is equal to the life of the plant, year (NOYR) = 15

42. Ratio of off-season price of paddy to the in-season price of dry paddy, (OSP) = 1.1305

43. Cost of fuel for drying of grain, Peso/litre (P1) = 3.25

44. Price of electricity, Peso/kW-hr (P2) = 1.0

45. Labor cost, Peso/hr/laborer (P3) = 2.025

46. Price of harvested wet grain at moisture

level of (GXM) % db, Peso/m^3 (P4) = 558.32

47. Price of dry grain during harvesting and drying season, Peso/m^3 (P5) = 725.096

48. Price of grain elevator per unit length in addition to (ELL), Peso (PEL) = 490.0

49. Yearly increase of grain price, Peso/m^3 (PI) = 36.228

50. Yearly price increase factor for repair and maintenance of the plant, decimal (PIF) = 0.02

51. Periodical price increase of fuel for grain drying, decimal (PIN) = 0.14

52. Periodical increase of price of electricity, decimal (PIN1) = 0.14

53. Yearly increase of price of labor, Peso/hr/laborer (PIX) = 0.291

54. Annual total price of one manager and one operator-cum-technician for operating seasons only, Peso (PMO) = 12600.0

55. Change in grain yield, decimal (PRI) = 0.26

56. Paddy production rate, m^3 (PRT) = 3.57

57. Property tax rate, decimal (PTR) = 0.03

58. Mean percentage of total working days during peak harvest, decimal (PTW) = 0.5

59. Net heating value of kerosene fuel for grain drying, kJ/litre (Q1) = 35667.2

60. Interest rate, decimal (RI) = 0.11

61. Critical level of rainfall for determination of sun-no sun conditions, mm (RN) = 5.0

62. Critical level of rainfall for determination of harvest-no harvest days, mm (RN1) = 5.0

63. Land rent rate, Peso/m^2/yr (RNTL) = 0.2

64. Sales tax rate, decimal (STR) = 0.01

65. Salvage value of concrete structures, decimal (SVC) = 0.15

66. Salvage value of the dryer, decimal (SVD) = 0.15

67. Salvage value of elevator/conveyor, decimal (SVE) = 0.15

68. Salvage value of storage structures, decimal (SVS) = 0.15

69. Time of grain drying -- single shift of plant operation, hr (TD) = 8.0

70. Total daily drying capacity of the dryers presently used within the service area of the plant, m^3/day (TDD) = 0.0

71. Temperature of drying air, ^{0}C (TH) = 80.0

72. Unit price of concrete structure or platform, Peso/m^2 (UPC) = 65.5

73. Unit price of dryer complete with all drying components, freight and installation costs, Peso/m^2/hr (UPD) = 35095.56

74. Unit price of land, Peso/m^2 (UPL) = 17.5

75. Unit price of electric motor, Peso/kW (UPM) = 1515.8

76. Unit price of storage structure, Peso/m^3 (UPS) = 327.5

77. Number of shifts of plant operation per day, each shift consists of (TD) hours, (WR) = 2.0

78. Miscellaneous cost, decimal of total variable cost (XC) = 0.005

79. Mean price of grain elevator (without motor) at less than or equal to (CBL), Peso (XPE1) = 4062.57

80. Mean price of grain elevator (without motor) at greater than (CBL), Peso (XPE2) = 4691.99

81. Mean percentage of total area to be harvested during peak harvest, decimal (YY) = 0.6

82. Time efficiency of solar radiation utilization, decimal (TF) = 0.9

83. Daily available mean solar hours, hr (DSH) = 7.0

84. Temperature of sundrying surfaces above ambient, ^0C (TC) = 10.0

85. Depth of grain to be used in sundrying, m (X1) = 0.02

86. Surface area that a laborer can cover effectively during natural sundrying, m2 (A2) = 200.0

C. Input Parameters and Constants Associated with Different Models

1. Model for Safe Storage Life of Grain (Page 54)

a (A) = $379.23 * 10^{10}$

u (B) = -6.6581

v (C) = -2.0393

t_g(ST) = 3.0 ^0C

2. Energy Cost of Grain Drying (Page 107)

C_{pa}(CPA) = 1.0 kJ/kg/^0C

C_{pv}(CPV) = 1.88 kJ/kg/^0C

P_a (PA) = 101283.98 Pa

R_e (RE) = 0.8

X (X) = 0.7 m

e_0 (EF) = 0.60

3. Equilibrium Temperature Model (Page 113)

b (B) = 51.16

c (C) = 0.000019187

n (AN) = 2.4451

4. The Latent Heat of Vaporization of Grain (Paddy) Moisture (Page 110)

b_2 (B2) = 2.323

b_3 (B3) = 1.026

b_4 (B4) = 2.9462

c_2 (C2) = 17.78

c_3 (C3) = 0.21733

5. Equilibrium Moisture Content (Page 112)

b (B) = 51.16

c (C) = 0.000019187

n (AN) = 2.4451

6. Determination of Grain Drying Constant (Page 112)

b_1 (B1) = 136485.6

c_1 (C1) = 4411.671

7. <u>Cost of Fan Operation for Moving Air through Grain During Drying</u> (Page 116)

$$q\ (A) = 3652.62$$

$$y\ (B) = 1.1867$$

$$e_1(E1) = 0.85$$

8. <u>Cost of Elevating/Conveying Grain</u> (Page 117)

$$e_2\ (E1) = 0.85$$

D. <u>Price of Dry Grain in Harvesting and Drying Season</u>

The market price of dry grain in a harvesting/drying season has been predicted using the past trend with an estimated regression equation as follows:

$$P_5 = -2245.6 + \underset{(3.7635)}{36.228}\ Y$$

$$(R^2 = 0.877,\ F = 92.665,\ S_{y.x} = 62.975)$$

where,

P_5 = Price of dry paddy in harvesting and drying season, Peso/m^3

Y = Year to be predicted -- 82 (1982, the base year)

E. Price of Wet Grain at Harvest

The price of wet grain (P_4) at maximum observed moisture content with a purity level of 90 to 95 % during harvest has been calculated using equivalent net weight factor for paddy (Gervacio, 1984, p.138) (Appendix G).

$$P_4 = 0.77 * P_5$$

F. Price of Dry Grain in Non-harvesting Seasons

The price of dry grain in a non-harvesting season was predicted using the past trend with an estimated regression equation as follows:

$$P_6 = -2645.1 + \underset{(4.0866)}{42.254}\, Y$$

$$(R^2 = 0.8916,\ F = 106.908,\ S_{y.x} = 68.383)$$

where,

P_6 = Price of dry grain in a non-harvesting season, Peso/m^3

Y = Year to be predicted -- 82 (1982, the base year)

G. Wage Rate

The wage rate of labor was predicted using the past trend with an estimated regression model as follows:

$$P_3 = -21.755 + 0.29\,Y$$
$$(0.04267)$$
$$(R^2 = 0.9394,\ F = 46.502,\ S_{y.x} = 0.134)$$

where,

P_3 = Labor price, Peso/hr/person

Y = Year to be predicted -- 82 (1982, the base year)

H. Unit Price of Dryer

The unit price of the dryer complete with all drying accessories, freight and installation costs has been calculated from information available in a research paper of Baloco (1980).

I. Unit Price of Electric Motor

The unit price of electric motor has been predicted using the information available in a manufacturer's price catalog (Seedburo, 1982). The estimated regression model is as follows:

$$P_m = \underset{(106.93)}{1515.8}\ K$$

$$(R^2 = 0.8731,\ F = 200.924,\ S_{y.x} = 518.14)$$

where,

P_m = Price of an electric motor, Peso

K = Electric power, kW

J. The Fitted Probability Distributions and Humidity-Temperature Models

The input parameters used in the fitted probability distributions and humidity-temperature models are shown in Table 2 and Table 3 respectively.

APPENDIX J

STEPS TO BE FOLLOWED WHILE USING THE MODEL

The following steps (refer to the program in Appendix L) need to be followed for successful use of the model.

1. Gather necessary data as mentioned in Appendix I and in the data statements of the program (Appendix L).
2. Read carefully the comment statements of the program and fit in appropriate data into the data statements (also see additional data statements in each subprogram).
3. Create a separate data file for historical data only, following the fixed format as mentioned in the READ (FORMAT) statement of the main program.
4. By careful observation of the historical weather data, select an appropriate choice (i.e. the value of KWD) of either historical air temperature and relative humidity data directly or generation of air temperature and relative humidity using fitted probability distributions. If the second choice is obvious, modification of several statements in the GNTH subprogram is a must.

5. Add extra WRITE statements if more output information is desired.
6. Run the program and get the result.

APPENDIX K

MODEL OUTPUT AT THE OPTIMUM LEVEL OF DRYING AND STORAGE CAPACITIES

YEAR	VARIABLE COST PESO	FIXED COST PESO	GRAIN COST PESO	REVENUE PESO	GRAIN LOSS PESO
1	29855.05	86712.87	522497.12	763289.50	0.00
2	26519.00	86784.87	414275.31	596712.50	0.00
3	29986.82	86858.37	531094.62	755350.87	0.00
4	29294.71	86933.31	473877.50	666319.87	0.00
5	39055.87	87009.75	699362.44	968346.87	3516.07
6	63621.85	87087.69	967950.81	1317277.00	0.00
7	47169.54	87167.19	791665.19	1072716.00	1564.38
8	45612.62	87249.31	766284.25	1036478.25	0.00
9	45967.78	87331.06	891217.44	1199608.00	0.00
10	52154.00	87415.44	879446.19	1172383.00	0.00
11	59361.44	87501.50	1008712.69	1329943.00	7718.33
12	150684.94	87589.31	1602037.00	2037329.00	3732.09
13	135190.31	87678.87	1593795.00	2027429.00	0.00
14	93045.69	87770.19	1152951.00	1470623.00	16670.95
15	180692.25	87863.37	1524792.00	1862455.00	47836.54

YEAR	HARVESTING DAYS	PLANT IN OPERATION DAYS	AVERAGE PLANT CAPACITY UTILIZATION	PLANT IN FULL CAPACITY,DAYS
1	61	35	0.67	14
2	69	32	0.57	1
3	62	40	0.56	10
4	69	31	0.58	3
5	61	38	0.66	12
6	56	44	0.74	4
7	51	33	0.73	9
8	60	38	0.65	1
9	65	38	0.70	3
10	62	39	0.65	3
11	53	43	0.63	13
12	61	53	0.66	20
13	59	49	0.72	19
14	64	36	0.73	14
15	61	44	0.76	16

YEAR	GRAIN SAVED BY ESTABLISHING THE PLANT(CU.METER)	COST OF DRYING PESO/CU.M.	ENERGY COST OF DRYING PESO/CU.M.
1	931.15	32.06	18.37
2	693.30	38.25	18.98
3	837.76	35.79	19.07
4	706.90	41.44	20.74
5	984.55	39.67	20.54
6	1302.45	48.85	23.40
7	949.30	46.54	21.51
8	939.08	48.57	27.52
9	1014.93	43.97	26.88
10	954.23	52.71	30.54
11	1014.95	54.87	29.99
12	1662.09	90.66	31.74
13	1596.92	94.66	30.01
14	1027.64	84.69	36.58
15	1379.34	131.00	37.29

YEAR	DRY GRAIN TO BE STORED IN THE 1ST SEASON(CU.M.)	DRY GRAIN TO BE STORED IN THE 2ND SEASON(CU.M.)	NET CASH FLOW PESO
1	500.20	430.96	109895.81
2	180.22	513.09	68564.94
3	469.39	368.37	97286.25
4	323.50	383.41	73886.12
5	451.73	532.82	126587.94
6	663.07	639.39	210837.87
7	376.11	637.46	133393.06
8	340.29	598.79	121681.69
9	467.04	578.49	153863.06
10	603.86	385.59	134394.31
11	549.07	532.82	163748.62
12	671.35	990.74	293992.81
13	801.90	795.03	297432.69
14	674.65	424.01	144902.00
15	946.49	432.85	156128.97

```
PRINCIPAL COST OF THE PLANT(PESO)=      612636.19
NET PRESENT VALUE(PESO) =         416888.31
BENEFIT COST RATIO =  1.676
PRESENT VALUE OF NET CASH INFLOW(PESO) =    1029524.50
TOTAL GRAIN LOSS, EXCEPT PROCESSING AND
HANDLING LOSS(PESO) =        81038.81
TOTAL GRAIN LOSS, EXCEPT PROCESSING AND
HANDLING LOSS(CU.M) =     79.95
PROCESSING AND HANDLING LOSS(CU.M) =     81.72
TOTAL GRAIN SAVED BY ESTABLISHING
THE PLANT(CU.M) =  15994.58
REVENUE LOSS DUE TO LIMITED STORAGE CAPACITY
OF THE PLANT DURING ITS LIFE(PESO) =      244587.94
STORAGE CAPACITY FOR DRY GRAIN(CU.M) =  579.00
STORAGE CAPACITY FOR WET GRAIN(CU.M) =  112.45
DRYING CAPACITY OF THE PLANT(CU.M/8 HRS) =  37.00
TYPE OF DRYER = BATCH OR CROSS-FLOW
CONTINUOUS DRYER
SUNNY DAY DURING HARVESTING SEASONS(%) =  59.70
HARVEST DAY DURING HARVESTING SEASONS(%) =  69.24
TOTAL NO SUN-NO SUN SEQUENCE DURING H.SEASONS=    256
DRYING AIR TEMPERATURE(O C) =  80.00
MAXIMUM AIRFLOW RATE(CU.M/SQ.M/S) =  0.031
DAILY MAXIMUM PLANT OPERATING HOURS(HR) = 16.00
DRY GRAIN PARTIALLY TO  20.00% MOISTURE(DB)
TOTAL AREA NECESSARY TO SET UP THE PLANT,
INCLUDING AREA FOR SUN DRYING(HECTARE) =  0.288
AREA NECESSARY FOR SUN DRYING(HECTARE) =  0.225
SERVICE AREA OF THE PLANT(ACTUAL MEAN
PRODUCTIVE LAND)(HECTARES)=      500.00
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APPENDIX L

THE COMPUTER PROGRAM OF THE MODEL

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1  14:41:12   9 JUL 85                          T544720.PEZIA2.FORT
C      *****************************************************************
C      *****************************************************************
C      **                                                             **
C      **  SIMULATION OF WEATHER EFFECT MINIMIZATION INVESTMENT       **
C      **     : AN APPLICATION TO GRAIN DRYING SYSTEM DESIGN          **
C      **          AND MANAGEMENT IN A DEVELOPING REGION              **
C      **                        ( WEGDM )                            **
C      **                                                             **
C      *****************************************************************
C      *****************************************************************
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C      A : CROSS-SECTIONAL AREA OF THE DRYER (SQ.METER)
C      A1 : SURFACE AREA FOR SUNDRYING OF GRAIN (SQ.METER)
C      A2 : SURFACE AREA THAT A LABORER CAN COVER EFFECTIVELY
C           DURING NATURAL SUNDRYING (SQ.METER)
C      A3 : CROSS-SECTIONAL AREA OF STORAGE FOR WET GRAIN
C           (SQ.METER)
C      A4 : CROSS-SECTIONAL AREA OF STORAGE FOR DRY GRAIN(SQ.METER)
C      ACH : AREA HARVESTED(SERVICE AREA OF THE PLANT) (HECTARE)
C      AFR : MAXIMUM AIRFLOW RATE NECESSARY TO DRY THE
C            GRAIN(CU.M./SQ.M./SEC)
C      AIP : ANNUAL INCREASE OF PAY OR SALARY, (DECIMAL)
C      AMO : MOISTURE CONTENT OF PARTIALLY DRIED GRAIN,DRIED BY
C            THE PLANT(% DB). THE DRYERS ARE USUALLY DESIGNED FOR
C            TEN POINT MOISTURE REMOVAL.
C      AOM(I,J) : MOISTURE CONTENT OF HARVESTED GRAIN(WET) % DB.
C      BCR : BENEFIT COST RATIO (DECIMAL)
C      BRK : MAXIMUM INCOME LIMIT WHERE CORPORATE INCOME TAX RATE
C            CHANGES(MONEY UNIT)
C      C1 : CRITICAL LEVEL OF SOLAR RADIATION FOR DETERMINATION
C           OF SUN-NO SUN DAYS(CAL/SQ.CM/DAY).
C      C2 : CRITICAL LEVEL OF SOLAR RADIATION FOR DETERMINATION
C           OF WORK-NO WORK DAYS FOR GRAIN HARVEST(CAL/SQ.CM/DAY).
C      C3 : CRITICAL LEVEL OF WIND SPEED FOR DETERMINATION
C           OF WIND-NO WIND DAYS FOR GRAIN HARVEST(KM/HR).
C      CBL : CAPACITY BRACKET OF THE ELEVATOR,NEEDED DURING
C            PURCHASE OF GRAIN ELEVATOR(CU.M./HR)
C      CC : CAPITAL CONSUMPTION(DEPRECIATION PLUS INTEREST ON
C           SALVAGE VALUE) ON FACILITIES AND EQUIPMENT (MONEY/YR)
C      CED(I,J) : DAILY ENERGY COST OF GRAIN DRYING BY THE PLANT
C                 (MONEY UNIT)
C      CIP : TOTAL INSURANCE PAYMENT (MONEY UNIT)
C      COG(I,J) : DAILY PURCHASE COST OF WET AND PARTIALLY DRIED
C                 GRAIN (MONEY UNIT)
C      COSF(I,J) : DAILY COST OF FAN OPERATION FOR MOVING AIR
C                  THROUGH GRAIN (MONEY UNIT)
C      COSE(I,J) : ENERGY COST OF ELEVATING GRAIN (MONEY UNIT)
C      COST(I,J) : DAILY LABOR COST EMPLOYED IN SUNDRYING(MONEY U)
C      CPA : SPECIFIC HEAT OF DRYING AIR, (KJ/KG/O C).
C      CPPI : TOTAL INVESTMENT COST(MONEY UNIT).
C      CPV : SPECIFIC HEAT OF WATER VAPOR,(KJ/KG/C C).
C      CRF : CAPITAL RECOVERY FACTOR.
C      CRM(J) : YEARLY COST OF REPAIR AND MAINTENANCE (MONEY UNIT)
C      CSL(I,J) : DAILY LOSS OF PARTIALLY DRIED(SUN) GRAIN DUE TO
C                 UNAVAILABILITY OF THE PLANT (MONEY UNIT)
C      CSLOS(J) : YEARLY LOSS OF REVENUE DUE TO LIMITED CAPACITY
C                 OF THE STORAGE (MONEY UNIT)
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C     CST : TOTAL SHELTER COST OF EQUIPMENTS. (MONEY UNIT)
C     CTAX : CORPORATE TAX (DECIMAL)
C     CTAX1 : CORPCRATE INCOME TAX RATE FOR IST BRACKET  (DECIMAL)
C     CTAX2 : CORPORATE INCOME TAX RATE FOR 2ND BRACKET  (DECIMAL)
C     CTF(J)  : YEARLY TOTAL FIXED COST (MONEY UNIT)
C     CUP(I,J) : DAILY CAPACITY UTILIZATION OF THE PLANT(DECIMAL)
C     DCOST(I,J)  : DAILY ENERGY COST OF PARTIALLY DRIED(BY SUN)
C                   GRAIN BY THE PLANT  (MONEY UNIT)
C     DDG : DENSITY OF DRY GRAIN AT FM % DB  (KG/CU.METER)
C     DDR : DAILY MAXIMUM DRYING RATE OF THE PLANT(CU.M/DAY).
C     DFGRN(I,J)  : AMOUNT OF PARTIALLY DRIED GRAIN ACTUALLY DRIED
C                   BY THE PLANT WHICH HAS COME FROM FARMERS'
C                   HOUSE(CU.METER).
C     DGRAIN(I,J)  : DAILY AMOUNT OF GRAIN DRIED BY THE PLANT(CU.M)
C     DH(I,J)  : AMOUNT OF HARVESTED GRAIN WITHIN THE PLANT
C                SERVICE AREA  (CU.METER/DAY)
C     DLOS(I,J)  : DAILY AMOUNT OF PARTIALLY DRIED(BY SUN) GRAIN
C                  LOSS DUE TO UNAVAILABILITY OF THE PLANT(CU.M)
C     DMOR : DAILY MAXIMUM PLANT OPERATING HOURS(HOURS).
C     DPLS(I,J)  : DAILY AMOUNT OF PARTIALLY DRIED(BY SUN) GRAIN
C                  DRIED BY THE PLANT  (CU. METER)
C     DR : DRYING CAPACITY OF THE PLANT(CU.M./TD HOURS)
C     DSC : STORAGE CAPACITY FOR DRY GRAIN  (CU.METER)
C     DSH : DAILY AVAILABLE MEAN SOLAR HOURS(HR.)
C     DWG : MEAN DENSITY OF HARVESTED(WET) GRAIN  (KG/CU.METER)
C     E1 : OVERALL EFFICIENCY OF FAN-MOTOR SYSTEM OR GRAIN
C          ELEVATOR/CONVEYOR (DECIMAL).
C     EF : OVERALL THERMAL EFFICIENCY OF THE DRYER (DECIMAL)
C     EH1 : HEIGHT OF GRAIN  ELEVATOR 1 (METER)
C     EH2 : HEIGHT OF GRAIN  ELEVATOR 2 (METER)
C     ELL : HEIGHT OR LENGTH BRACKET OF THE ELEVATOR, NEEDED
C           DURING PURCHASE(METER)
C     ESH : EFFECTIVELY USED SOLAR HOURS PER DAY(HRS.)
C     FCN(J)  : YEARLY NET CASH FLOW  (MONEY UNIT)
C     FCOST(I,J)  : DAILY ENERGY COST OF PARTIALLY DRIED GRAIN
C                   COMING FROM FARMERS' HOUSE  (MONEY UNIT)
C     FE : HEIGHT INCREMENT FACTOR FOR GRAIN ELEVATORS(CONSTANT).
C     FGRN(I,J)  : DAILY AMOUNT OF GRAIN FLOWING TO THE FARMERS'
C                  HOUSE  (CU.METER)
C     FGRNP(I,J)  : DAILY FLOW OF PARTIALLY DRIED GRAIN FROM
C                   FARMERS' HOUSE TO THE PLANT  (CU.METER)
C     FL : EXTRA LAND THAT MIGHT BE NECESSARY FOR ROAD, LOADING
C          UNLOADING AREA, MISC. USE ETC.  (SQ.METER)
C     FLOSS(I,J)  : LOSS OF PARTIALLY DRIED GRAIN DUE TO UNAVAIL-
C                   ABILITY OF THE PLANT,COMING FROM FARMERS' HOUSE
C                   (MONEY UNIT)
C     FLOSX(I,J)  : LOSS OF PARTIALLY DRIED GRAIN DUE TO
C                   UNAVAILABILITY OF THE PLANT, GRAIN COMMING
C                   FROM FARMERS' HOUSE  (CU.METER)
C     FM : FINAL MOISTURE(SAFE STORAGE LEVEL) CONTENT OF THE
C          GRAIN  (% DB).
C     FMCG(I,J)  : MOISTURE CONTENT OF PARTIALLY DRIED GRAIN
C                  COMING FROM FARMERS' HOUSE (% DB).
C     GCOST(J)  : YEARLY TOTAL COST OF GRAIN DRYING  (MONEY/YEAR)
C     GCOSTP(J)  : YEARLY TOTAL OPERATING COST OF THE PLANT(MONEY/YR)
C     GIM : MINIMUM MOISTURE CONTENT OF GRAIN AT HARVEST,(% DB).
C     GLOT : TOTAL GRAIN LOSS,EXCEPT PROCESSING AND HANDLING LOSS
C            DURING ENTIRE LIFE OF THE PLANT(CU.M)
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C      GRAIN(I,J) : DAILY GRAIN FLOW TO THE PROCESSING PLANT(CU.M)
C      GSAV(J) : AMOUNT OF GRAIN SAVED IN YEAR J DUE TO
C                ESTABLISHMENT OF THE PLANT (CU.METER)
C      GSAVT : TOTAL GRAIN SAVED BY ESTABLISHING THE PLANT DURING
C              ENTIRE LIFE OF THE PLANT(CU.M)
C      GSUM(I,J) : DAILY TOTAL AMOUNT OF GRAIN READY TO STORE(CU.M)
C      GXM : MAXIMUM MOISTURE CONTENT OF GRAIN AT HARVEST,(% DB)
C      H(I,J) : DAILY AVERAGE OF AIR RELATIVE HUMIDITY(HISTORICAL)
C      HQL : GRAIN HANDLING AND QUALITY LOSS DURING ENTIRE
C            PROCESSING OPERATION(DECIMAL)
C      HUM : DAILY MEAN AIR RELATIVE HUMUDITY, (%)
C      IDATE(M) : CUMULATIVE NO. OF DAYS ON MONTHLY DENOMINATION.
C      IDAY : DAY OF THE MONTH. EXAMPLES 30,31,29,28 ETC.
C      IF1 : FIRST DAY OF 1ST HARVESTING SEASON, DAY OF THE YEAR.
C      IF2 : FIRST DAY OF 2ND HARVESTING SEASON, DAY OF THE YEAR.
C      IFULL(J) : NO. OF DAYS PLANT IN OPERATION WITH FULL CAPACITY.
C      IFY : BEGINNING YEAR OF INPUT WEATHER DATA MINUS ONE EXMP.
C            (59-1)=58
C      IHD(J) : TOTAL HARVESTING DAYS IN A YEAR, DAYS
C      IL1 : LAST DAY OF 1ST HARVESTING SEASON, DAY OF THE YEAR.
C      IL2 : LAST DAY OF 2ND HARVESTING SEASON, DAY OF THE YEAR.
C      INN : TOTAL NO. OF NO SUN-NO SUN SEQUENCE DURING HARVESTING
C            SEASONS FOR ENTIRE SIMULATED PERIOD. NO SUN-NO SUN
C            SEQUENCE MEANS NO SUN TODAY AND NO SUN TOMORROW.
C      IPO(J) : TOTAL PLANT OPERATING DAYS IN A YEAR, DAYS.
C      ISUN(I,J) : GENERATED DAILY SUN-NO SUN STATES (1-0)
C      IWIND(I,J) : GENERATED DAILY NO WIND-WIND STATES(1-0)
C      IWORK(I,J) : GENERATED DAILY WORK-NO WORK STATES (1-0)
C      IYR : YEAR, EXAMPLE 83 FOR 1983.
C      KFD : NO OF FUTURE BAD(WEATHER) DAYS THAT FARMERS MAY WAIT
C            FOR SUNDRYING BEFORE THEY DECIDE TO SELL THEIR GRAIN
C            TO THE PLANT. EXAMPLE FOR NO SUN TODAY-NO SUN
C            TOMORROW KFD=1,FOR NO SUN TODAY-NO SUN TOMORROW-NO
C            SUN DAY AFTER TOMORROW KFD=2 ETC. PLEASE CHOOSE
C            ONE VALUE.
C      KSD : IT'S AN INDICATOR FOR DRYING OF PARTIALLY DRIED
C            GRAIN. KSD=1 MEANS PARTIALLY(BY PLANT) DRIED
C            GRAIN IS DRIED BY THE PLANT. IF PLANT IS
C            NOT AVAILABLE, IT IS REDRIED BY SUN.
C            KSD=2 MEANS PARTIALLY(BY PLANT) DRIED GRAIN IS
C            REDRIED BY SUN. IF SUN IS NOT AVAILABLE,
C            IT IS DRIED BY THE PLANT. PLEASE CHOOSE ONE VALUE.
C      KSY : IT'S AN INDICATOR FOR GRAIN SALE. KSY=1 MEANS
C            ALL DRY GRAIN IS SOLD OUT AT THE END OF EACH DRYING
C            SEASON. KSY=2 MEANS ALL DRY GRAIN IS SOLD OUT ONLY AT
C            THE END OF EACH YEAR. PLEASE CHOOSE ONE VALUE.
C      KWD : IT'S AN INDICATOR.KWD=1 MEANS HISTORICAL WEATHER DATA
C            IS USED DIRECTLY AS A SUBSTITUTE OF GENERATION
C            OF DAILY TEMP & HUMIDITY,ASSUMING SAME WEATHER
C            PATTERN WILL PERSIST IN FUTURE. KWD=2 MEANS HISTORICAL
C            WEATHER DATA IS USED TO GENERATE DAILY TEMP &
C            HUMIDITY USING PRE-FITTED PROBABILITY DISTRIBUTION.
C            PLEASE CHOOSE ONE VALUE.
C      LY : END OF YEAR OF INPUT WEATHER DATA PLUS ONE, EXAMPLE,
C           (83+1)=84
C      M1 : TIME SPAN BETWEEN TWO SUCCESSIVE YEARS OF CHANGE OF
C           GRAIN PRODUCTION (YEAR).
C      M2 : TIME SPAN IN YEARS BETWEEN TWO SUCCESSIVE YEARS OF
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C           PRICE CHANGE OF ELECTRICITY.
C       M3 : TIME SPAN IN YEARS BETWEEN TWO SUCCESSIVE YEARS OF
C           PRICE CHANGE OF FUEL FOR GRAIN DRYING.
C       N : TOTAL NO. OF HISTORICAL YEARS USED IN INPUT WEATHER DATA
C       NDAY(M) : NO.OF DAYS IN A MONTH.
C       NOS : NO OF GRAIN HARVESTING SEASONS IN A YEAR.
C       NOYP : NO OF SIMULATED YEAR THAT IS EQUAL TO THE LIFE
C             OF THE DRYING PLANT(YEARS).
C       OM : MOISTURE CONTENT OF THE HARVESTED GRAIN (% DB)
C       OSP : RATIO OF OFF-SEASON GRAIN(DRY) PRICE TO THE
C            IN-SEASON GRAIN(DRY) PRICE.
C       P1 : COST OF FUEL FOR DRYING OF GRAIN(MONEY/UNIT),
C           EXAMPLE PESO PER LITRE.
C       P2 : PRICE OF ENERGY(ELECTRICITY) (MONEY UNIT/KW-HR)
C       P3 : LABOR COST (MONEY UNIT/HR/LABORER)
C       P4 : PRICE OF HARVESTED(WET) GRAIN AT MOISTURE LEVEL
C           OF GXM % DB (MONEY UNIT/CU.M)
C       P5 : PRICE OF DRY GRAIN DURING HARVESTING AND DRYING
C           SEASON. (MONEY UNIT/CU.METER).
C       PA : ATMOSPHERIC PRESSURE (PASCAL)
C       PCS : PRICE OF CONCRETE STRUCTURES (MONEY UNIT)
C       PD : PURCHASE PRICE OF THE DRYER UNIT,INCLUDES HEATER,
C           MOTOR,FAN,CONVEYERS ETC.(MONEY UNIT)
C       PE : PRICE OF GRAIN ELEVATOR (MONEY UNIT)
C       PEL : PRICE OF GRAIN ELEVATOR PER UNIT LENGTH IN
C            ADDITION TO ELL(MONEY UNIT)
C       PEM1 : PRICE OF ELECTRIC MOTOR 1 (MONEY UNIT)
C       PEM2 : PRICE OF ELECTRIC MOTOR 2 (MONEY UNIT)
C       PHAR : PERCENT OF HARVESTING DAY DURING HARVESTING
C             SEASONS FOR ENTIRE SIMULATED PERIOD.
C       PHL : TOTAL PROCESSING AND HANDLING LOSS DURING
C            ENTIRE LIFE OF THE PLANT(CU.M)
C       PI : YEARLY INCREASE OF GRAIN PRICE(MONEY UNIT/CU.M.).
C       PIF : YEARLY PRICE INCREASE FACTOR FOR REPAIR AND MAINTE
C            NANCE OF THE PLANT(DECIMAL)
C       PIN : PERIODICAL PRICE INCREASE OF FUEL FOR GRAIN
C            DRYING,(DECIMAL).
C       PIN1 : PERIODICAL INCREASE OF PRICE OF ENERGY(ELECTRICITY)
C             PRICE(DECIMAL).
C       PIX : YEARLY INCREASE OF PRICE OF LABOR,
C            (MONEY UNIT/HR/LABORER).
C       PL : PRICE OF LAND(MONEY UNIT)
C       PLNT(I,J) : DAILY AMOUNT OF GRAIN DRIED BY THE PLANT(WET
C                  GRAIN+PARTIALLY DRIED GRAIN) (CU.METER)
C       PLC(I,J) : DAILY LOSS OF GRAIN DUE TO LIMITED CAPACITY
C                 OF THE DRYING PLANT (MONEY UNIT)
C       PMO : ANNUAL TOTAL PRICE OF ONE MANAGER AND AN OPERATOR-CUM-
C            TECHNICIAN FOR OPERATING SEASONS ONLY WITH AN ANNUAL
C            INCREASE, AT A RATE OF AIP (MONEY UNIT).
C       PRI : CHANGES IN GRAIN YIELD (DECIMAL)
C       PROBS(I,J) : MARKOV TRANSITIONAL PROBABILITIES FOR SUN
C                   NO SUN CONDITIONS.
C       PROBW(I,J) : MARKOV TRANSITIONAL PROBABILITIES FOR WORK
C                   NO WORK CONDITIONS.
C       PROBWI(I,J) : MARKOV TRANSITIONAL PROBABILITIES FOR
C                    NO WIND-WIND CONDITIONS.
C       PRT : GRAIN PRODUCTION RATE (CU.METER/HECTARE)
C       PST : PRICE OF STORAGE BIN FOR DRY GRAIN(MONEY UNIT)
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C      PSUN : PERCENT OF SUNNY DAYS DURING HARVESTING
C              SEASONS FOR ENTIRE SIMULATED PERIOD.
C      PSW : PRICE OF STORAGE BIN FOR WET GRAIN (MONEY UNIT)
C      PTR : PROPERTY TAX RATE (DECIMAL)
C      PTW : MEAN PERCENTAGE OF TOTAL WORKING DAYS DURING PEAK
C            HARVEST,(DECIMAL).
C      PVL : PRESENT VALUE OF LAND (MONEY UNIT)
C      PVN : NET PRESENT VALUE OF THE ENTIRE PROJECT (MONEY UNIT)
C      PVR : PRESENT VALUE OF REVENUE EARNED (MONEY UNIT)
C      PVRNT : PRESENT VALUE OF LAND RENTAL COST (MONEY UNIT)
C      PVSR : PRESENT VALUE OF PLANT SALVAGE REVENUE (MONEY UNIT)
C      Q1 : NET HEATING VALUE OF FUEL USED FOR GRAIN DRYING
C           (KJ/UNIT). EXAMPLE KJ/LITRE.
C      QF(I,J) : DAILY AIRFLOW RATE NECESSARY TO DRY THE GRAIN,
C                (CU.METER/SQ.M./SEC).
C      QFP(I,J) : DAILY AIRFLOW RATE NECESSARY TO DRY THE PARTIALLY
C                 DRIED GRAIN COMING FROM FARM HOUSE(CU.M/SQ.M./S)
C      QFS(I,J) : DAILY AIRFLOW RATE NECESSARY TO DRY PARTIALLY
C                 DRIED(SUN) GRAIN (CU.M/SQ.M/SEC)
C      RA(I,J) : GENERATED DAILY AIR RELATIVE HUMIDITY (DECIMAL)
C      RAIN : DAILY RAINFALL, (MM)
C      RE : EXHAUST AIR RELATIVE HUMIDITY OF DRYING AIR (DECIMAL)
C      REV(L,J) : SEASONAL REVENUE EARNED (MONEY UNIT)
C      RI : INTEREST RATE (DECIMAL)
C      RN : CRITICAL LEVEL OF RAINFALL FOR DETERMINATION OF
C           SUN-NO SUN CONDITIONS(MM).
C      RN1 : CRITICAL LEVEL OF RAINFALL FOR DETERMINATION OF
C            WORK-NO WORK DAYS FOR HARVESTING OF GRAIN(MM).
C      RNTL : LAND RENT RATE (MONEY UNIT/SQ.M/YEAR)
C      RSV : TOTAL SALVAGE VALUE OF EQUIPMENT AND FACILITIES.(M.U.)
C      S(I,J) : HISTORICAL SUN-NO SUN DAYS.
C      SAV(I,J) : DAILY AMOUNT OF GRAIN SAVED DUE TO ESTABLISHMENT
C                 OF THE PLANT (CU.METER)
C      SCALE : SCALE PARAMETER OF THE FITTED DISTRIBUTION.
C      SHAPE : SHAPE PARAMETER OF THE FITTED DISTRIBUTION.
C      SLOS(L,J) : SEASONAL LOSS OF REVENUE DUE TO LIMITED CAPACITY
C                  OF THE STORAGE FACILITIES FOR DRY GRAIN
C      SOLAR : DAILY SOLAR RADIATION, (CAL/SQ.CM./DAY).
C      ST : TEMPERATURE INCREMENT OF STORAGE GRAIN ABOVE
C           AMBIENT (O C).
C      STR : SALES TAX RATE (DECIMAL)
C      SUMG(L,J) : SEASONAL TOTAL DRY GRAIN READY TO STORE(CU.METER)
C      SVC : SALVAGE VALUE OF CONCRETE STRUCTURES (DECIMAL)
C      SVD : SALVAGE VALUE OF THE DRYER UNIT (DECIMAL)
C      SVE : SALVAGE VALUE OF ELEVATOR.(DECIMAL)
C      SVS : SALVAGE VALUE OF STORAGE STRUCTURES (DECIMAL)
C      SWC : CAPACITY OF STORAGE FOR WET GRAIN (CU.METER)
C      T(I,J) : HISTORICAL DAILY MEAN AIR TEMPERATURE (O C)
C      TA(I,J) : GENERATED DAILY AMBIENT TEMPERATURE (O C)
C      TC : SURFACE TEMPERATURE OF SUNDRYING PLATFORM OR SURFACE
C           ABOVE AMBIENT (O C).
C      TCG(J) : YEARLY PURCHASE COST OF WET AND PARTIALLY DRIED
C               GRAIN (MONEY UNIT)
C      TCOST(I,J) : DAILY TOTAL COSTS (MONEY UNIT)
C      TD : TIME OF DRYING(SINGLE SHIFT OF PLANT OPERATION) (HOURS).
C      TDD : TOTAL DAILY DRYING CAPACITY OF THE DRYERS PRESENTLY
C            USED WITHIN THE SERVICE AREA OF THE PLANT(CU.M/DAY).
C      TDEP : TOTAL DEPRECIATION COST PER YEAR (MONEY UNIT)
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```
C       TEMN : DAILY MINIMUM TEMPERATURE O C, EXAMPLE 25.7 O C.
C       TEMX : DAILY MAXIMUM TEMPERATURE O C, EXAMPLE 30.5 O C.
C       TF : TIME EFFICIENCY OF SOLAR RADIATION UTILIZATION (DECIMAL)
C       TH : TEMPERATURE OF DRYING AIR, (O C).
C       TIP : TOTAL INTEREST PAYMENT PER YEAR (MONEY UNIT)
C       TPLA : TOTAL AREA NECESSARY TO SET UP THE DRYING
C              PLANT (HECTARE).
C       TREV(J) : YEARLY REVENUE EARNED (MONEY UNIT)
C       TXP : TOTAL TAX PAYMENT (MONEY UNIT)
C       UCOST(J) : ENERGY COST OF GRAIN DRYING ONLY (MONEY/CU.M.)
C       UPC : UNIT PRICE OF CONCRETE STRUCTURE(PLATFORM)(MON./SQ.M)
C       UPD : UNIT PRICE OF THE DRYER COMPLETE WITH ALL DRYING
C             COMPONENTS AND INCLUDE FREIGHT AND INSTALLATION COSTS
C             (MONEY UNIT/CU.M./HR)
C       UPL : UNIT PRICE OF LAND (MONEY UNIT/SQ.METER)
C       UPM : UNIT PRICE OF ELECTRIC MOTOR (MONEY UNIT/KW)
C       UPS : UNIT PRICE OF STORAGE STRUCTURE (MONEY UNIT/CU.METER)
C       UTCST(J) : UNIT COST OF GRAIN DRYING (MONEY/CU.M.)
C       VCOST(J) : YEARLY TOTAL VARIABLE COST (MONEY UNIT)
C       W(I,J) : HISTORICAL WORK-NO WORK DAYS (1-0)
C       WI(I,J) : DAILY WIND SPEED(HISTORICAL), (KPH).
C       WIND : DAILY WIND SPEED, (KM/HR). EXAMPLE 5.6 KPH..
C       WR : NO OF SHIFTS OF PLANT OPERATION PER DAY,EACH SHIFT
C            CONSISTS OF TD HOURS.
C       X : DEPTH OF GRAIN IN THE DRYER (METER)
C       X1 : DEPTH OF GRAIN TO BE USED IN SUNDRYING (METER)
C       XLOCA : LOCATION PARAMETER OF THE FITTED DISTRIBUTION.
C       XC : MISCELLANEOUS COST, DECIMAL OF TOTAL VARIABLE OR
C            OPERATING COST OF THE PLANT(DECIMAL).
C       XPE1 : MEAN PRICE OF GRAIN ELEVATOR(WITHOUT MOTOR) AT LESS
C              THAN OR EQUAL TO CEL(MONEY UNIT)
C       XPE2 : MEAN PRICE OF GRAIN ELEVATOR(WITHOUT MOTOR) AT
C              GREATER THAN CBL(MONEY UNIT)
C       XSUM(J) : YEARLY TOTAL AMOUNT OF GRAIN READY TO STORE (CU.M.)
C       YCUP(J) : MEAN CAPACITY UTILIZATION OF THE PLANT
C                 DURING PLANT OPERATION.
C       YGL(J) : YEARLY GRAIN LOSS (MONEY UNIT)
C       YGLOS(J) : YEARLY GRAIN LOSS INCLUDING STORAGE LOSS(M.U.)
C       YGLT : TOTAL GRAIN LOSS(EXCEPT PROCESSING AND HANDLING
C              LOSS DURING ENTIRE LIFE OF THE PLANT(MONEY UNIT)
C       YSUMG(I,J) : YEARLY TOTAL DRY GRAIN READY TO STORE(CU.M.)
C       YY : MEAN PERCENT OF TOTAL AREA TO BE HARVESTED DURING
C            PEAK HARVEST,(DECIMAL).
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
      BLOCK DATA
      COMMON /AA/IDATE(12),NDAY(12)
      COMMON /CC/XLOCA(12),SCALE(12),SHAPE(12)
      DATA IDATE/0,31,59,90,120,151,181,212,243,273,304,334/
      DATA NDAY/31,28,31,30,31,30,31,31,30,31,30,31/
      DATA XLOCA/24.9499,0.0,21.3445,0.0,0.0,28.3008,22.9514,
     *27.4519,27.365,0.0,0.0,21.1176/
      DATA SCALE/0.698483,25.958,5.79268,28.7535,29.408,0.623223,
     *5.13038,0.596543,0.555387,27.4178,26.8475,4.81893/
      DATA SHAPE/0.0,23.7895,4.65088,32.6476,29.1899,0.0,5.29442,
     *0.0,0.0,33.0084,29.2884,4.28437/
      END
```

```
C
C       ***********************************************************
C
C
        DATA A1/2250.0/,A3/25.0/,A4/50.0/,ACH/500.0/,AIP/0.05/
        DATA AMO/20.0/,BRK/100000.0/,C1/250.0/,C2/110.0/,C3/15.0/
        DATA CBL/10.6/,CTAX1/0.25/,CTAX2/0.35/,DDG/572.26/,DR/37.0/
        DATA DSC/579.0/,DSEED/60768.D0/,DWG/642.54/,ELL/3.05/,FE/1.1/
        DATA FL/500.0/,FM/14.0/,GIM/26.0/,GXM/30.0/,HQL/0.005/
        DATA IFY/58/,IF1/232/,IF2/311/,IL1/274/
        DATA IL2/355/,KFD/1/,KSD/1/,KSY/1/,KWD/1/,LY/84/,M1/10/,M2/2/
        DATA M3/2/,N/25/,NOS/2/,NOYR/15/,OSP/1.1305/,P1/3.25/
        DATA P2/1.0/,P3/2.025/,P4/558.32/,P5/725.096/,PEL/490.0/
        DATA PI/36.228/,PIF/0.02/,PIN/0.14/,PIN1/0.14/
        DATA PIX/0.291/,PMO/12600.0/,PRI/0.26/,PRT/3.57/,PT3/0.03/
        DATA PTW/0.5/,Q1/35667.2/,RI/0.11/,RN/5.0/,RN1/5.0/
        DATA RNTL/0.2/,STR/0.01/
        DATA SVC/0.15/,SVD/0.15/,SVE/0.15/,SVS/0.15/,TD/8.0/
        DATA TDD/0.0/,TH/80.0/,UPC/65.5/,UPD/35905.56/,UPL/17.5/
        DATA UPM/1515.8/,UPS/327.5/,WR/2.0/,XC/0.005/
        DATA XPE1/4062.57/,XPE2/4691.99/,YY/0.6/
C
C
C       SEE FOR MORE DATA IN THE BEGINNING OF THE APPROPRIATE
C       SUBROUTINE SUBPROGRAMS BELOW.
C
C       ***********************************************************
C
C
        COMMON /AA/IDATE(12),NDAY(12)
        COMMON /BB/TA(365,15),RA(365,15)
        COMMON /CC/XLOCA(12),SCALE(12),SHAPE(12)
        COMMON /DD/DGRAIN(365,15),DLOS(365,15)
        COMMON /EE/COST(365,15),DCOST(365,15),PLNT(365,15),
       *DPLS(365,15),CSL(365,15),QFS(365,15)
        COMMON /FF/FMCG(365,15),DFGEN(365,15),COSM(365,15)
        COMMON /GG/IWORK(365,15),GRAIN(365,15)
        COMMON /HH/ISUN(365,15)
        COMMON /RR/K1(15),K2(15)
        COMMON /OO/FGEN(365,15)
        COMMON /PP/FGENP(365,15)
        COMMON /TT/PLO(365,15),GLO(365,15)
        COMMON /SS/AOM(365,15)
        COMMON /WW/T(365,25),H(365,25)
        COMMON /ZZ/IWIND(365,15)
C
C
        DIMENSION S(365,25),W(365,25),PROBS(365,4),
       *PROBW(365,4),PROBWI(365,4),WI(365,25),YSUMG(15),
       *IPO(15),YCUP(15),IHD(15),IFULL(15),
       *CED(365,15),QF(365,15)
       *,FLOSS(365,15),FCOST(365,15),QFP(365,15),CUP(365,15)
       *,COSF(365,15),VCOST(15),FCN(15),YGL(15),YGLOS(15)
       *,GSUM(365,15),SUMG(2,15),SLOS(2,15),CSLOS(15),TCOST(365,15)
       *,REV(2,15),TREV(15),COG(365,15),TCG(15),CRM(15),CTF(15)
       *,GCOST(15),XSUM(15),UCOST(15),UTCST(15),SAV(365,15),GSAV(15)
       *,FLOSX(365,15),GCOSTP(15)
C
```

```
C
C     ************************************************************
C     *                                                          *
C     *                      PART I : SPWV                       *
C     *                                                          *
C     *          SIMULATION PROGRAM FOR WEATHER VARIABLES        *
C     *                                                          *
C     ************************************************************
C
      CALL INT1(N,S,T,PROBS)
      CALL INT1(N,W,H,PROBW)
      DO 18 J=1,N
      DO 19 I=1,365
      WI(I,J)=9999.0
   19 CONTINUE
   18 CONTINUE
   50 CONTINUE
      READ(10,100,END=200) IYR,MON,IDAY,TEMN,TEMX,HUM,
     *RAIN,SOLAR,WIND
  100 FORMAT(1X,I2,1X,I2,1X,I2,5X,F4.1,1X,F4.1,1X,F5.1,1X,F5.1,
     *1X,F5.1,1X,F5.1)
      IF(MON.EQ.2.AND.IDAY.GE.29) GO TO 50
      AVTEM=(TEMN+TEMX)/2
      IF(SOLAR.GT.C1.AND.RAIN.LT.RN) GO TO 60
      SUN=0.0
      GO TO 70
   60 SUN=1.0
   70 CONTINUE
      IF(SOLAR.GT.C2.AND.RAIN.LT.RN1) GO TO 80
      WORK=0.0
      GO TO 90
   80 WORK=1.0
   90 CONTINUE
      IF(WIND.GT.C3) GO TO 86
      WINDY=1.0
      GO TO 87
   86 WINDY=0.0
   87 CONTINUE
      KDATE=IDATE(MON) + IDAY
      LYR=IYR - IFY
      T(KDATE,LYR)=AVTEM
      H(KDATE,LYR)=HUM
      S(KDATE,LYR)=SUN
      W(KDATE,LYR)=WORK
      WI(KDATE,LYR)=WINDY
      IF(IYR.LT.LY) GO TO 50
  200 CONTINUE
      CALL BREAK(N,S,PROBS)
      CALL BREAK(N,W,PROBW)
      CALL BREAK(N,WI,PROBWI)
C     THIS PART OF THE PROGRAM IS FOR GENERATION OF TWO
C     STATE CONDITIONS. THAT IS SUN-NO SUN AND HARVEST-NO HARVEST
C     AND NO WIND-WIND STATES AS INDICATED BY 1-0
      CALL STATE(NOYR,DSEED,PROBS,ISUN)
      CALL STATE(NOYR,DSEED,PROBW,IWORK)
      CALL STATE(NOYR,DSEED,PROBWI,IWIND)
      IF(KWD.EQ.1) GO TO 299
      CALL GNTH(NOYR)
```

```
       GO TO 399
 299   CALL HTH(NOYR)
C
C      *************************************************************
C      *                                                           *
C      *                     PART II : SPGDM                       *
C      *                                                           *
C      *        SIMULATION PROGRAM FOR GRAIN FLOW,DRYING           *
C      *                   AND MANAGEMENT                          *
C      *                                                           *
C      *************************************************************
C
 399   CALL YGRN(NOYR,KPD,TDD,PTW,YY,GXM,GIM,IF1,IF2,IL1,IL2,
     *ACH,PRT,PRI,M1,ISD,INN)
       CALL FHGRN(NOYR,TDD,FM,FMCG)
       CALL GLOSS(NOYR,PI,P4,P5,DR,WR,GIM,GXM,FM,TA,GRAIN,DGRAIN,
     *SWC,DDR)
       IKK=0
       DO 110 J=1,NOYR
       IKK=IKK+K1(J)+K2(J)
       DO 210 I=1,365
       CED(I,J)=0.0
       QF(I,J)=0.0
 210   CONTINUE
 110   CONTINUE
       IDH=((IL1-IF1)+(IL2-IF2)+2)*NOYR
       PSUN=(ISD*100.0)/IDH
       PHAR=(IKK*100.0)/IDH
       PO=P1
       DO 310 J=1,NOYR
       DO 410 I=1,365
       IF(DGRAIN(I,J).EQ.0.0) GO TO 410
       DG1=DGRAIN(I,J)
       TA1=TA(I,J)
       RA1=RA(I,J)
       IF(RA1.LE.1.0) GO TO 325
       RA1=1.0
 325   CONTINUE
       OM=AOM(I,J)
       CALL ECOST(TA1,RA1,DR,TD,TH,DDG,DG1,P1,OM,AMO,Q1,QA,CED1,A)
       QF(I,J)=QA
       CED(I,J)=CED1
 410   CONTINUE
       IF(M3.EQ.1) GO TO 312
       N2=J/M3
       K22=M3*N2+1
       IF(J.EQ.1) GO TO 310
       IF(J.EQ.K22) GO TO 312
       GO TO 310
 312   P1=P1+P1*PIN
 310   CONTINUE
       P1=PO
       IF(KSD.EQ.1) GO TO 199
       CALL CSD1(NOYR,TD,TH,M3,Q1,PIN,PIX,P3,P4,P5,FM,GXM,DDR,DR,
     *DDG,PI,P1,AMC,A1)
       GO TO 198
 199   CALL CSD2(NOYR,TD,TH,M3,Q1,PIN,PIX,P3,P4,P5,FM,GXM,DDR,DR,
     *DDG,PI,P1,AMO,A1)
```

```
 198  CONTINUE
C     THIS PORTION OF THE PROGRAM CALCULATES THE COST OF
C     DRYING OF PARTIALLY DRIED GRAIN BY THE PLANT AND THE VALUE
C     OF LOST GRAIN DUE TO GRAIN FLOW FROM FARMERS' HOUSE
      P0=P1
      PM=P4
      PN=P5
      DO 201 J=1,NOYR
      DO 301 I=1,365
      FLOSS(I,J)=0.0
      FLOSX(I,J)=0.0
      FCOST(I,J)=0.0
      QFF(I,J)=0.0
      DFGRN(I,J)=0.0
      TA1=TA(I,J)
      RA1=RA(I,J)
      FG=FGRNP(I,J)
      CM=FMCG(I,J)
      IF(FG.EQ.0.0) GO TO 301
      IF(PLNT(I,J).EQ.DDR.OR.DGRAIN(I,J).EQ.DDR) GO TO 401
      IF(PLNT(I,J).GT.0.0.OR.DGRAIN(I,J).GT.0.0) GO TO 601
      IF(FG.GT.DDR) GO TO 701
      CALL ECOST(TA1,RA1,DR,TD,TH,DDG,FG,P1,CM,FM,Q1,QBA,COSTA,A)
      FCOST(I,J)=COSTA
      QFF(I,J)=QBA
      DFGRN(I,J)=FG
      GO TO 301
 401  FLOSS(I,J)=FG*(P4+((P5-P4)/(GXM-FM))*(GXM-CM))
      FLOSX(I,J)=FG
      GO TO 301
 701  EXX=(FG-DDR)
      CALL ECOST(TA1,RA1,DR,TD,TH,DDG,DDR,P1,CM,FM,Q1,QBB,COSTB,A)
      FLOSS(I,J)=EXX*(P4+((P5-P4)/(GXM-FM))*(GXM-CM))
      FLOSX(I,J)=EXX
      FCOST(I,J)=COSTB
      QFF(I,J)=QBB
      DFGRN(I,J)=DDR
      GO TO 301
 601  IF(PLNT(I,J).GT.0.0) GO TO 162
      XEX=(DDR-DGRAIN(I,J))
      GO TO 163
 162  XEX=(DDR-PLNT(I,J))
 163  IF(FG.GT.XEX) GO TO 602
      CALL ECOST(TA1,RA1,DR,TD,TH,DDG,FG,P1,CM,FM,Q1,QBC,COSTC,A)
      FCOST(I,J)=COSTC
      QFF(I,J)=QBC
      DFGRN(I,J)=FG
      GO TO 301
 602  CALL ECOST(TA1,RA1,DR,TD,TH,DDG,XEX,P1,CM,FM,Q1,QBD,COSTD,A)
      FLOSS(I,J)=(FG-XEX)*(P4+((P5-P4)/(GXM-FM))*(GXM-CM))
      FLOSX(I,J)=FG-XEX
      FCOST(I,J)=COSTD
      QFF(I,J)=QBD
      DFGRN(I,J)=XEX
 301  CONTINUE
      IF(M3.EQ.1) GO TO 377
      N2=J/M3
      K22=M3*N2+1
```

```
      IF(J.EQ.1) GO TO 277
      IF(J.EQ.K22) GO TO 377
      GO TO 277
  377 P1=P1+P1*PIN
  277 P5=P5+PI
      P4=P4+PI
  201 CONTINUE
      P1=PO
      P4=PM
      P5=PN
C     THIS PORTION OF THE PROGRAM CALCULATES THE COST OF
C     OPERATING FAN FOR MOVING AIR THROUGH GRAIN DURING DRYING
      PQ=P2
      DO 801 J=1,NOYR
      DO 901 I=1,365
      DG11=DGRAIN(I,J)
      Q11=QF(I,J)
      DP11=DPLS(I,J)
      Q22=QFS(I,J)
      FG11=DPGRN(I,J)
      Q33=QFF(I,J)
      COSF(I,J)=0.0
      IF(DG11.EQ.0.0) GO TO 909
      CALL CFAN(P2,TD,Q11,DG11,COF1)
      COSF(I,J)=COF1
  909 IF(DP11.EQ.0.0) GO TO 907
      CALL CFAN(P2,TD,Q22,DP11,COF2)
      COSF(I,J)=COSF(I,J)+COF2
  907 IF(FG11.EQ.0.0) GO TO 901
      CALL CFAN(P2,TD,Q33,FG11,COF3)
      COSF(I,J)=COSF(I,J)+COF3
  901 CONTINUE
      IF(M2.EQ.1) GO TO 836
      N2=J/M2
      K22=M2*N2+1
      IF(J.EQ.1) GO TO 801
      IF(J.EQ.K22) GO TO 836
      GO TO 801
  836 P2=P2+P2*PIN1
  801 CONTINUE
C     THIS PORTION OF THE PROGRAM CALCULATES THE MAXIMUM AIRFLOW
C     NECESSARY TO DRY THE GRAIN.
      AFR1=0.0
      AFR3=0.0
      AFR5=0.0
      DO 174 J=1,NOYR
      DO 176 I=1,365
      L=I
      M=J
      IF(I.EQ.365) GO TO 274
      GO TO 374
  274 L=0
      IF(J.NE.NOYR) M=J+1
  374 AFR2=AMAX1(QF(I,M),QF(L+1,M))
      AFR1=AMAX1(AFR1,AFR2)
      AFR4=AMAX1(QFF(I,M),QFF(L+1,M))
      AFR3=AMAX1(AFR3,AFR4)
      AFR6=AMAX1(QFS(I,M),QFS(L+1,M))
```

```
      AFR5=AMAX1(AFR5,AFR6)
 176  CONTINUE
 174  CONTINUE
      AFR=AMAX1(AFR1,AFR3,AFR5)
      P2=PQ
      EH1=(SWC/A3)*FE
      EH2=(DSC/A4)*FE
      OM=(GXM+GIM)/2
      CALL CEG(NOYR,TD,M2,PIN1,EH1,EH2,P2,DDG,DWG,DR,OM,FM,
     *AMO,PE1,PE3)
C     THIS PART OF THE PROGRAM CALCULATES THE TOTAL AMOUNT
C     OF DRY GRAIN THAT NEED TO BE STORED DURING A DRYING
C     SEASON.
      DO 101 J=1,NOYR
      DO 102 L=1,NOS
      SUMG(L,J)=0.0
      SLOS(L,J)=0.0
 102  CONTINUE
 101  CONTINUE
      DO 103 J=1,NOYR
      DO 104 I=1,365
C     THE FOLLOWING STATEMENT INDICATES THE TIME SPAN BETWEEN
C     TWO STARTING PIONTS OF THE SUCCESSIVE HARVESTING SEASONS
      IF(I.GT.232.AND.I.LE.310) GO TO 31
      L=2
      GO TO 51
  31  L=1
  51  GSUM(I,J)=DGRAIN(I,J)+DFGRN(I,J)-DLOS(I,J)
     *-HQL*(DGRAIN(I,J)+DFGRN(I,J))
      SUMG(L,J)=SUMG(L,J)+GSUM(I,J)
 104  CONTINUE
 103  CONTINUE
C     THIS PORTION OF THE PROGRAM CALCULATES THE LOSS DUE TO
C     INSUFFICIENT STORAGE CAPACITY AND TOTAL REVENUE.
      IF(KSY.EQ.2) GO TO 939
      DO 105 J=1,NOYR
      CSLOS(J)=0.0
      TREV(J)=0.0
      DO 106 L=1,NOS
      IF(SUMG(L,J).LT.DSC)  GO TO 203
      SLOS(L,J)=(SUMG(L,J)-DSC)*(OSP*P5-P5)
      CSLOS(J)=CSLOS(J)+SLOS(L,J)
      REV(L,J)=DSC*OSP*P5+(SUMG(L,J)-DSC)*P5
      GO TO 204
 203  REV(L,J)=SUMG(L,J)*OSP*P5
 204  TREV(J)=TREV(J)+REV(L,J)
 106  CONTINUE
      P5=P5+PI
 105  CONTINUE
      GO TO 119
 939  DO 129 J=1,NOYR
      CSLOS(J)=0.0
      TREV(J)=0.0
      YSUMG(J)=0.0
      DO 229 L=1,NOS
      YSUMG(J)=YSUMG(J)+SUMG(L,J)
 229  CONTINUE
      IF(YSUMG(J).LT.DSC)  GO TO 224
```

```
      CSLOS(J)=(YSUMG(J)-DSC)*(OSP*P5-P5)
      TREV(J)=DSC*OSP*P5+(YSUMG(J)-DSC)*P5
      GO TO 129
  224 TREV(J)=YSUMG(J)*OSP*P5
      P5=P5+PI
  129 CONTINUE
  119 P5=PN
C     CALCULATE THE AMOUNT OF GRAIN COULD BE SAVED BY
C     ESTABLISHING THE DRYING PLANT.
      KFD1=KFD+1
      DO 190 J=1,NOYR
      DO 192 I=1,365
      SAV(I,J)=0.0
      IF(GRAIN(I,J).EQ.0.0) GO TO 192
      OM=AOM(I,J)
      TAA=TA(I,J)
      CALL SSLG(TAA,OM,SS)
      IX1=IFIX(SS)
      XZ0=SS-IX1
      IF(XZ0.GT.0.5) IX1=IX1+1
      IF(KFD1.GT.IX1) GO TO 193
      GO TO 192
  193 SAV(I,J)=GRAIN(I,J)
  192 CONTINUE
  190 CONTINUE
      GSAVT=0.0
      PHL=0.0
      DO 194 J=1,NOYR
      GSAV(J)=0.0
      DO 195 I=1,365
      GSAV(J)=GSAV(J)+SAV(I,J)+FGRNP(I,J)-GLO(I,J)-DLOS(I,J)
     *-FLOSX(I,J)-HQL*(DGRAIN(I,J)+DFGRN(I,J))
      PHL=PHL+HQL*(DGRAIN(I,J)+DFGRN(I,J))
  195 CONTINUE
      GSAVT=GSAVT+GSAV(J)
  194 CONTINUE
C
C     **************************************************************
C     *                                                            *
C     *                      PART III : SPFA                       *
C     *                                                            *
C     *          SIMULATION PROGRAM FOR FINANCIAL ANALYSIS         *
C     *                                                            *
C     **************************************************************
C
C     THIS PORTION OF THE PROGRAM CALCULATES THE SUM OF SOME
C     OPERATING COST OF THE PLANT AND THE COST OF THE GRAIN.
      DO 107 J=1,NOYR
      TCG(J)=0.0
      DO 108 I=1,365
      OM=AOM(I,J)
      TCOST(I,J)=PLO(I,J)+CED(I,J)+COST(I,J)+CSL(I,J)+DCOST(I,J)
     *+FLOSS(I,J)+FCOST(I,J)+COSF(I,J)+COSM(I,J)
      COG(I,J)=(GRAIN(I,J)*P4)+FGRNP(I,J)*(P4+((P5-P4)/(OM-FM))*
     $(OM-FMCG(I,J)))
      TCG(J)=TCG(J)+COG(I,J)
  108 CONTINUE
      P5=P5+PI
```

```
      P4=P4+PI
  107 CONTINUE
      P4=PM
      P5=PN
C     THIS PORTION OF THE PROGRAM CALCULATES TOTAL VARIABLE COSTS
C     , THE YEARLY GRAIN LOSS , THE DAILY CAPACITY UTILIZATION
C     OF THE GRAIN PROCESSING PLANT AND UNIT COST OF GRAIN DRYING
      PMOI=0.0
      YGLT=0.0
      YGLOST=0.0
      GLOT=0.0
      CSLOST=0.0
      DO 71 J=1,NOYR
      IPO(J)=0
      YCUP(J)=0.0
      YGL(J)=0.0
      IFULL(J)=0
      GCOST(J)=0.0
      XSUM(J)=0.0
      VCOST(J)=CSLOS(J)
      DO 72 I=1,365
      VCOST(J)=VCOST(J)+TCOST(I,J)
      GCOST(J)=GCOST(J)+CED(I,J)+COST(I,J)+DCOST(I,J)+FCOST(I,J)
     *+COSP(I,J)+COSM(I,J)
      XSUM(J)=XSUM(J)+GSUM(I,J)
      GLOT=GLOT+GLO(I,J)+DLOS(I,J)+FLOSX(I,J)
      YGL(J)=YGL(J)+(PLO(I,J)+CSL(I,J)+FLOSS(I,J))
      CUP(I,J)=(DGRAIN(I,J)+DFGRN(I,J)+DPLS(I,J))/DDR
      IF(CUP(I,J).GT.0.0) GO TO 154
      GO TO 72
  154 IPO(J)=IPO(J)+1
      IF(CUP(I,J).EQ.1) GO TO 436
      GO TO 438
  436 IFULL(J)=IFULL(J)+1
  438 YCUP(J)=YCUP(J)+CUP(I,J)
   72 CONTINUE
      GCOSTP(J)=(GCOST(J)+(PMO+PMOI*(J-1)))
      YGLT=YGLT+YGL(J)
      VCOST(J)=(VCOST(J)+(PMO+PMOI*(J-1)))
      YGLOS(J)=YGL(J)+CSLOS(J)
      YGLOST=YGLOST+YGLOS(J)
      CSLOST=CSLOST+CSLOS(J)
      YCUP(J)=YCUP(J)/IPO(J)
      UCOST(J)=GCOST(J)/XSUM(J)
      IHD(J)=K1(J)+K2(J)
      PMOI=AIP*PMO
   71 CONTINUE
      DO 333 J=1,NOYR
      VCOST(J)=VCOST(J)*(1+XC)
      UTCST(J)=VCOST(J)/XSUM(J)
  333 CONTINUE
      DMOR=TD*WR
C     THIS PORTION OF THE PROGRAN CALCULATES THE PRINCIPAL
C     COST OF THE PLANT COMPONENT
      DR1=(DR/TD)
      PD=(DR/TD)*UPD
      PSW=SWC*UPS
      PSD=DSC*UPS
```

```
C      CALCULATE THE COST OF GRAIN ELEVATOR
       IF(DR1.GT.CBL) GO TO 706
       IF(EH1.GT.ELL) GO TO 606
       EP1=XPE1
       GO TO 607
  606  EP1=XPE1+PEL*(EH1-ELL)
  607  IF(EH2.GT.ELL) GO TO 608
       EP2=XPE1
       GO TO 609
  608  EP2=XPE1+PEL*(EH2-ELL)
       GO TO 609
  706  IF(EH1.GT.ELL) GO TO 803
       EP1=XPE2
       GO TO 802
  803  EP1=XPE2+PEL*(EH2-ELL)
  802  IF(EH2.GT.ELL) GO TO 807
       EP2=XPE2
       GO TO 609
  807  EP2=XPE2+PEL*(EH2-ELL)
  609  PE=EP1+EP2
       IF(AMO.LE.FM) A1=0.0
       PL=(A+A1+A3+A4+FL)*UPL
       PCS=(A+A1+A3+A4)*UPC
       PEM1=PE1*UPM
       PEM2=PE3*UPM
       CPRL=(PD+PSW+PSD+PE+PL+PCS+PEM1+PEM2)
C      **********************************************************
C      CALCULATE THE FIXED COST OF THE PLANT COMPONENTS.
C      CALCULATE DEPRECIATION USING CAPITAL RECOVERY
C      FACTOR(CRF).
       CRF=(RI*(1+RI)**NOYR)/((1+RI)**NOYR-1)
       TDEP=((PD-SVD*PD)+(PE-SVE*PE)+(PSW-SVS*PSW)+(PSD-SVS*PSD)
      $+(PCS-SVC*PCS)+((PEM1+PEM2)-SVD*(PEM1+PEM2)))*CRF
C      CALCULATE CAPITAL CONSUMPTION(DEPRECIATION PLUS INTEREST
C      ON SALVAGE VALUE) ON FACILITIES AND EQUIPMENT.
       CC=TDEP+(SVD*PD+SVE*PE+SVS*PSW+SVS*PSD+SVC*PCS
      $+SVD*(PEM1+PEM2))*RI
C      CALCULATE TAXES.
       TXP=(STR/NOYR+0.25*PTR)*CPRL
C      CALCULATE INSURANCE COST
       CIP=0.0025*(CPRL-PL-PCS)
C      CALCULATE SHELTER COST
       CST=0.0075*(PD+PE+PEM1+PEM2)
C      CALCULATE LUBRICATION,REPAIR AND MAINTENANCE COST.
       PINF=1.0
       DO 81 J=1,NOYR
       CRM(J)=0.02*(PD+PE+PEM1+PEM2)*PINF
       PINF=PINF*(1+PIF)
   81  CONTINUE
C      CALCULATE TOTAL FIXED COST.
       DO 88 J=1,NOYR
       CTF(J)=(CC+TXP+CIP+CST)+CRM(J)
   88  CONTINUE
       RSV=SVD*PD+SVE*PE+SVS*PSW+SVS*PSD
      $+SVC*PCS+SVD*(PEM1+PEM2)
C      CALCULATE YEARLY NET CASHFLOW(WITH DEDUCTION OF
C      CORPORATE TAX).
       DO 197 J=1,NOYR
```

```
      FCN(J)=((TREV(J)-TCG(J))-(GCOSTP(J)+CTF(J))-TDEP)
      IF(FCN(J).LE.BRK)  GO TO 519
      FCN(J)=((TREV(J)-TCG(J))-(GCOSTP(J)+CTF(J))-TDEP)*
     $(1-CTAX1)+(FCN(J)-BRK)*(1-CTAX2)+TDEP
      GO TO 197
 519  FCN(J)=((TREV(J)-TCG(J))-(GCOSTP(J)+CTF(J))-TDEP)*
     $(1-CTAX1)+TDEP
 197  CONTINUE
C     **************************************************************
C     CALCULATE PRESENT VALUE
      PVR=0.0
      DO 707 J=1,NOYR
C     CALCULATE PRESENT VALUE OF NET CASH FLOW.
      PVR=PVR+(FCN(J)/((1+RI)**J))
 707  CONTINUE
C     CALCULATE PRESENT VALUE OF PLANT SALVAGE REVENUE
      PVSR=PSV/((1+RI)**NOYR)
      RNT=RNTL*(A+A1+A3+A4+FL)
      TPLA=(A+A1+A3+A4+FL)/10000.0
      TPLS=A1/10000.0
      PVRNT=0.0
C     CALCULATE PRESENT VALUE OF LAND COST(OPPORTUNITY COST
C     OF LAND:RENT OF LAND)
      DO 941 J=1,NOYR
      PVRNT=PVRNT+RNT/((1+RI)**J)
 941  CONTINUE
      VLD=PL*(1+RI)**NOYR
      PVL=VLD/((1+RI)**NOYR)
C     CALCULATE NET PRESENT VALUE OF THE ENTIRE PROJECT.
      PVCI=PVR+PVSR+PVL-PVRNT
      PVN=PVR+PVSR+PVL-PVRNT-CPRL
      BCR=(PVR+PVSR+PVL)/(PVRNT+CPRL)
C     **************************************************************
      WRITE(11,811)
 811  FORMAT(1X,'YEAR',2X,'VARIABLE COST',3X,'FIXED COST',4X,
     *'GRAIN COST',4X,'REVENUE',6X,'GRAIN LOSS')
      WRITE(11,573)
 573  FORMAT(11X,'PESO',11X,'PESO',11X,'PESO',9X,'PESO',
     *10X,'PESO')
      DO 950 J=1,NOYR
      WRITE(11,850) J,VCOST(J),CTF(J),TCG(J),TREV(J),YGL(J)
 850  FORMAT(2X,I2,5(F14.2))
 950  CONTINUE
      WRITE(11,861)
 861  FORMAT(1X,'YEAR',2X,'HARVESTING',2X,'PLANT IN OPERATION'
     *,2X,'AVERAGE PLANT CAPACITY',2X,'PLANT IN FULL')
      WRITE(11,862)
 862  FORMAT(11X,'DAYS',12X,'DAYS',13X,'UTILIZATION',8X,
     *'CAPACITY,DAYS')
      DO 951 J=1,NOYR
      WRITE(11,571) J,IHD(J),IPO(J),YCUP(J),IFULL(J)
 571  FORMAT(2X,I2,8X,I3,12X,I3,16X,F5.2,16X,I3)
 951  CONTINUE
      WRITE(11,696)
 696  FORMAT(1X,'YEAR',3X,'GRAIN SAVED BY ESTABLISHING',
     *3X,'COST OF DRYING',3X,'ENERGY COST OF DRYING')
      WRITE(11,979)
 979  FORMAT(10X,'THE PLANT(CU.METER)',11X,'PESO/CU.M.',
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     *13X,'PESO/CU.M.')
      DO 669 J=1,NOYR
      WRITE(11,698) J,GSAV(J),UTCST(J),UCOST(J)
 698  FORMAT(2X,I2,9X,F10.2,14X,F10.2,14X,F10.2)
 669  CONTINUE
      WRITE(11,721)
 721  FORMAT(1X,'YEAR',2X,'DRY GRAIN TO BE STORED IN'
     *,3X,'DRY GRAIN TO BE STORED IN',3X,'NET CASH FLOW')
      WRITE(11,722)
 722  FORMAT(10X,'THE 1ST SEASON(CU.M.)',5X,
     *'THE 2ND SEASON(CU.M.)',7X,'PESO')
      DO 723 J=1,NOYR
      WRITE(11,698) J,SUMG(1,J),SUMG(2,J),FCN(J)
 723  CONTINUE
      WRITE(11,551) CPRL
 551  FORMAT(2X,'PRINCIPAL COST OF THE PLANT(PESO)=',F15.2)
      WRITE(11,451) PVN
 451  FORMAT(2X,'NET PRESENT VALUE(PESO) =',F18.2)
      WRITE(11,452) BCR
 452  FORMAT(2X,'BENEFIT COST RATIO =',F7.3)
      WRITE(11,556) PVCI
 556  FORMAT(2X,'PRESENT VALUE OF NET CASH INFLOW(PESO) =',F14.2)
      WRITE(11,222)
 222  FORMAT(2X,'TOTAL GRAIN LOSS, EXCEPT PROCESSING AND')
      WRITE(11,223) YGLT
 223  FORMAT(2X,'HANDLING LOSS(PESO) =',F15.2)
      WRITE(11,222)
      WRITE(11,226) GLOT
 226  FORMAT(2X,'HANDLING LOSS(CU.M) =',F10.2)
      WRITE(11,225) PHL
 225  FORMAT(2X,'PROCESSING AND HANDLING LOSS(CU.M) =',F10.2)
      WRITE(11,227)
 227  FORMAT(2X,'TOTAL GRAIN SAVED BY ESTABLISHING')
      WRITE(11,228) GSAVT
 228  FORMAT(2X,'THE PLANT(CU.M) =',F10.2)
      WRITE(11,221)
 221  FORMAT(2X,'REVENUE LOSS DUE TO LIMITED STORAGE CAPACITY')
      WRITE(11,230) CSLOST
 230  FORMAT(2X,'OF THE PLANT DURING ITS LIFE(PESO) =',F15.2)
      WRITE(11,555) DSC
 555  FORMAT(2X,'STORAGE CAPACITY FOR DRY GRAIN(CU.M) =',F8.2)
      WRITE(11,453) SWC
 453  FORMAT(2X,'STORAGE CAPACITY FOR WET GRAIN(CU.M) =',F8.2)
      WRITE(11,661) DR
 661  FORMAT(2X,'DRYING CAPACITY OF THE PLANT(CU.M/8 HRS) =',F7.2)
      WRITE(11,454)
 454  FORMAT(2X,'TYPE OF DRYER = BATCH OR CROSS-FLOW')
      WRITE(11,552)
 552  FORMAT(2X,'CONTINUOUS DRYER ')
      WRITE(11,888) PSUN
 888  FORMAT(2X,'SUNNY DAY DURING HARVESTING SEASONS(%) =',F7.2)
      WRITE(11,889) PHAR
 889  FORMAT(2X,'HARVEST DAY DURING HARVESTING SEASONS(%) =',F7.2)
      WRITE(11,887) INN
 887  FORMAT(2X,'TOTAL NO SUN-NO SUN SEQUENCE DURING H.SEASONS=',I7)
      WRITE(11,664) TH
 664  FORMAT(2X,'DRYING AIR TEMPERATURE(O C) =',F7.2)
      WRITE(11,455) AFR
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      455  FORMAT(2X,'MAXIMUM AIRFLOW RATE(CU.M/SQ.M/S) =',F7.3)
           WRITE(11,662) DMOR
      562  FORMAT(2X,'DAILY MAXIMUM PLANT OPERATING HOURS(HR) =',F6.2)
           WRITE(11,663) AMO
      663  FORMAT(2X,'DRY GRAIN PARTIALLY TO',F7.2,'% MOISTURE(DB)')
           WRITE(11,763)
      763  FORMAT(2X,'TOTAL AREA NECESSARY TO SET UP THE PLANT,')
           WRITE(11,456) TPLA
      456  FORMAT(2X,'INCLUDING AREA FOR SUN DRYING(HECTARE) =',F7.3)
           WRITE(11,777) TPLS
      777  FORMAT(2X,'AREA NECESSARY FOR SUN DRYING(HECTARE) =',F7.3)
           WRITE(11,764)
      764  FORMAT(2X,'SERVICE AREA OF THE PLANT(ACTUAL MEAN')
           WRITE(11,765) ACH
      765  FORMAT(2X,'PRODUCTIVE LAND)(HECTARES)= ',F10.2)
           STOP
           END
C
C          ************************************************************
           SUBROUTINE INT1(N,R,R1,PROB)
C          SUBROUTINE FOR INITIALIZATION OF MATRICES
           DIMENSION R(365,25),PROB(365,4),R1(365,25)
           DO 100 J=1,N
           DO 50 I=1,365
           R(I,J)=9999.0
           R1(I,J)=9999.0
       50  CONTINUE
      100  CONTINUE
           DO 200 I=1,365
           DO 150 J=1,4
           PROB(I,J)=0.0
      150  CONTINUE
      200  CONTINUE
           RETURN
           END
C
C          ************************************************************
           SUBROUTINE BREAK(N,R,PROB)
C          SUBROUTINE FOR CALCULATION OF MARKOV
C          TRANSITION PROBABILITIES.
           DIMENSION R(365,25),PROB(365,4)
           DO 600 I=1,N
           DO 500 J=1,365
           L=J
           M=I
           IF(J.EQ.365) GO TO 10
           GO TO 20
       10  L=0
           IF(I.NE.N) M=I + 1
       20  IF(R(J,I).EQ.9999.0.OR.R(L+1,M).EQ.9999.0) GO TO 600
           IF(R(J,I).EQ.1.0.AND.R(L+1,M).EQ.1.0) GO TO 100
           IF(R(J,I).NE.1.0.AND.R(L+1,M).EQ.1.0) GO TO 200
           IF(R(J,I).EQ.1.0.AND.R(L+1,M).NE.1.0) GO TO 300
           IF(R(J,I).NE.1.0.AND.R(L+1,M).NE.1.0) GO TO 400
      100  PROB(L+1,1)=PROB(L+1,1)+1
           GO TO 500
      200  PROB(L+1,2)=PROB(I+1,2)+1
           GO TO 500
```

```
  300   PROB(L+1,3)=PROB(L+1,3)+1
        GO TO 500
  400   PROB(L+1,4)=PROB(L+1,4)+1
  500   CONTINUE
  600   CONTINUE
C       CALCULATE MARKOV TRANSITION MATRIX
        DO 700 I=1,365
        SUM=0.0
        SUM=PROB(I,1) + PROB(I,3)
        IF(SUM.EQ.0.0) GO TO 650
        PROB(I,1)=PROB(I,1)/SUM
        PROB(I,3)=1 - PROB(I,1)
  650   SUM=PROB(I,2) + PROB(I,4)
        IF(SUM.EQ.0.0) GO TO 700
        PROB(I,2)=PROB(I,2)/SUM
        PROB(I,4)=1 - PROB(I,2)
  700   CONTINUE
        RETURN
        END
C
C       ************************************************************
        SUBROUTINE STATE(NOYR,DSEED,PROB,ISTATE)
C       SUBROUTINE FOR DETERMINATION OF TWO STATE CONDITIONS SUCH
C       AS SUN-NO SUN, HARVEST-NO HARVEST,NO WIND-WIND AS INDICATED
C       BY 1-0. YEAR NO. 1 MEANS THE BEGINING OF THE IST YEAR.
        DIMENSION PROB(365,4),P(2,2),ISTATE(365,15)
        DOUBLE PRECISION DSEED
        DSEE=DSEED
        R=GGUBFS(DSEED)
        IS=R+1.5
        DO 300 J=1,NOYR
        DO 200 I=1,365
        P(1,1)=PROB(I,1)
        P(1,2)=PROB(I,3)
        P(2,1)=PROB(I,2)
        P(2,2)=PROB(I,4)
        R=GGUBFS(DSEED)
        IF(R.GT.P(IS,2)) GO TO 40
        IS=2
        ISTATE(I,J)=0
        GO TO 200
   40   IS=1
        ISTATE(I,J)=1
  200   CONTINUE
  300   CONTINUE
        DSEED=DSEE
        RETURN
        END
C
C       ************************************************************
        SUBROUTINE GNTH(NOYR)
C       THIS IS AN OPTIONAL SUBROUTINE.
C       THE PROGRAM FOR GENERATION OF DAILY AVERAGE TEMPERATUSE
C       AND RELATIVE HUMIDITY OF AMBIENT AIR.
        COMMON /AA/IDATE(12),NDAY(12)
        COMMON /BB/TA(365,15),RA(365,15)
        COMMON /CC/XLOCA(12),SCALE(12),SHAPE(12)
C       GENERATE DAILY TEMPERATURE AND RELATIVE HUMIDITY OF AIR
```

```
      DOUBLE PRECISION DSEED
      DSEED=123457.D0
      DO 250 J=1,NOYR
      DO 450 I=1,365
      TA(I,J)=0.0
      RA(I,J)=0.0
  450 CONTINUE
  250 CONTINUE
      DO 200 J=1,NOYR
      DO 800 MON=1,12
      N=NDAY(MON)
      X=XLOCA(MON)
      B=SCALE(MON)
      A=SHAPE(MON)
      DO 700 I=1,N
      KDATE=IDATE(MON)+I
      IF(MON.EQ.1.OR.MON.EQ.6) GO TO 500
      IF(MON.EQ.8.OR.MON.EQ.9) GO TO 500
C     THE FOLLOWING STATEMENT GENERATES DAILY TEMPERATURE WEIBULL
C     WEIBULL DISTRIBUTION(PREVIOUSLY FITTED AND TESTED)
  405 R=GGUBFS(DSEED)
      IF(R.EQ.0.0.OR.R.EQ.1.0) GO TO 405
      TA1=X+B*((-ALOG(1-R))**(1/A))
      GO TO 550
  500 CONTINUE
C     THE FOLLOWING STATEMENTS GENERATE DAILY TEMPERATURE FROM
C     LOGISTIC DISTRIBUTION(PREVIOUSLY FITTED AND TESTED)
  505 R=GGUBFS(DSEED)
      IF(R.EQ.0.0.OR.R.EQ.1.0) GO TO 505
      TA1=X+B*(-ALOG((1/R)-1))
  550 TA(KDATE,J)=TA1
      IF(MON.GE.2.AND.MON.LE.4) GO TO 300
      IF(MON.GE.5.AND.MON.LE.10) GO TO 350
      CALL HUMNA(TA1,RA1)
      GO TO 400
  300 CONTINUE
      CALL HUMNB(TA1,RA1)
      GO TO 400
  350 CONTINUE
      CALL HUMMO(TA1,RA1)
  400 RA(KDATE,J)=RA1
  700 CONTINUE
  800 CONTINUE
  200 CONTINUE
      RETURN
      END
C
C     ************************************************************
      SUBROUTINE HUMNB(TA,RA)
C     SUBROUTINE FOR GENERATION OF RELATIVE HUMIDITY OF AIR
C     FOR THE MONTHS OF FEBRUARY TO APRIL,USING REGRESSION MODEL
C     BASED ON HISTORICAL WEEKLY DATA
      DATA C/39.53/,D/1022.30/
      Z=(C+D/TA)
      RA=Z/100
      RETURN
      END
C
```

```
C       ************************************************************
        SUBROUTINE HUMMO(TA,RA)
C       SUBROUTINE FOR GENERATION OF RELATIVE HUMIDITY OF AIR
C       FOR THE MONTHS OF MAY TO OCTOBER,USING REGRESSION MODEL
C       BASED ON HISTORICAL WEEKLY DATA.
C       C,D ARE REGRESSION COEFFICIENTS.
        DATA C/185.82/,D/-3.6994/
        Z=(C+D*TA)
        RA=Z/100
        RETURN
        END
C
C       ************************************************************
        SUBROUTINE HUMNA(TA,RA)
C       SUBROUTINE FOR GENERATION OF RELATIVE HUMIDITY OF AIR
C       FOR THE MONTHS OF NOVEMBER, DECEMBER AND JANUARY,
C       USING REGRESSION HISTORICAL MODEL BASED ON WEEKLY DATA.
        DATA C/115.31/,D/-793.54/
        Z=(C+D/TA)
        RA=Z/100
        RETURN
        END
C
C       ************************************************************
        SUBROUTINE HTH(NOYR)
C       SUBROUTINE FOR USE OF TEMP.& HUMIDITY DATA DIRECTLY FROM
C       HISTORICAL DATA,ASSUMING TEMP.& HUMIDITY WILL BE SAME AS
C       IN THE PAST.
        COMMON /BB/TA(365,15),RA(365,15)
        COMMON /WW/T(365,25),H(365,25)
        DO 200 J=1,NOYR
        DO 300 I=1,365
        TA(I,J)=0.0
        RA(I,J)=0.0
        TA(I,J)=T(I,J)
        RA(I,J)=H(I,J)/100
        IF(RA(I,J).GE.1.0) RA(I,J)=0.98
  300   CONTINUE
  200   CONTINUE
        RETURN
        END
C
C       ************************************************************
        SUBROUTINE YGRN(NOYR,KPD,TDD,PTW,YY,GXM,GIM,IF1,IF2,IL1,IL2,
       *ACH,PRT,PRI,M1,ISD,INN)
C       THE SUBROUTINE FOR GRAIN INFLOW TO THE DRYING PLANT
        COMMON /GG/IWORK(365,15),GRAIN(365,15)
        COMMON /HH/ISUN(365,15)
        COMMON /OO/FGRN(365,15)
        COMMON /RR/K1(15),K2(15)
        COMMON /SS/AOM(365,15)
        COMMON /ZZ/IWIND(365,15)
        DIMENSION DH(365,15)
        DIMENSION NP(15),NH1(15),NP1(15),NH2(15),NP2(15),
       *AL1(15),AL2(15)
        DOUBLE PRECISION DSEED
        DSEED=123457.D0
        PRT1=PRT
```

```
      DO 569 J=1,NOYR
      DO 669 I=1,365
      L=I
      M=J
      IF(I.EQ.1.AND.J.EQ.1) GO TO 669
      IF(IWIND(I,J).EQ.0) GO TO 269
      GO TO 569
  269 IF(I.EQ.1) GO TO 169
      GO TO 769
  169 L=366
      M=J-1
  769 IWORK(L-1,M)=1
  669 CONTINUE
  569 CONTINUE
      ISD=0
      INN=0
      DO 610 J=1,NOYR
      K1(J)=0
      K2(J)=0
      DO 710 I=1,365
      L=I
      M=J
      IF(I.EQ.365) GO TO 208
      GO TO 207
  208 L=0
      IF(J.NE.NOYR) M=J+1
  207 CONTINUE
C     THE FOLLOWING TWO STATEMENTS DEFINE THE PERIOD OF
C     HARVESTING SEASONS PER YEAR.
      IF(I.GT.IF1.AND.I.LT.IL1) GO TO 910
      IF(I.GT.IF2.AND.I.LT.IL2) GO TO 911
      GO TO 710
  910 CONTINUE
      IF(ISUN(I,J).EQ.1) ISD=ISD+1
      IF(ISUN(I,J).EQ.0.AND.ISUN(L+1,M).EQ.0) INN=INN+1
      IF(IWORK(I,J).EQ.0) GO TO 710
      K1(J)=K1(J)+1
      GO TO 710
  911 CONTINUE
      IF(ISUN(I,J).EQ.1) ISD=ISD+1
      IF(ISUN(I,J).EQ.0.AND.ISUN(L+1,M).EQ.0) INN=INN+1
      IF(IWORK(I,J).EQ.0) GO TO 710
      K2(J)=K2(J)+1
  710 CONTINUE
  610 CONTINUE
      DO 100 J=1,NOYR
      TW1=PTW*K1(J)
      NP(J)=IFIX(TW1)
      TH1=(K1(J)-TW1)/2
      NH1(J)=IFIX(TH1)
      NX=K1(J)-(NP(J)+2*NH1(J))
      NP1(J)=NP(J)+NX
      TW2=PTW*K2(J)
      NP(J)=IFIX(TW2)
      TH2=(K2(J)-TW2)/2
      NH2(J)=IFIX(TH2)
      NX=K2(J)-(NP(J)+2*NH2(J))
      NP2(J)=NP(J)+NX
```

```
 100  CONTINUE
      TAB=ACH*YY
      TA=(ACH-TAB)/2
      DO 110 J=1,NOYR
      NN=0
      MM=0
      DO 210 I=1,365
      AOM(I,J)=0.0
      DH(I,J)=0.0
C     THE FOLLOWING TWO STATEMENTS DEFINE THE PERIOD OF
C     HARVESTING SEASONS PER YEAR.
      IF(I.GT.IF1.AND.I.LT.IL1) GO TO 810
      IF(I.GT.IF2.AND.I.LT.IL2) GO TO 811
      GO TO 210
 810  IF(IWORK(I,J).EQ.0) GO TO 210
      R=GGUBFS(DSEED)
      AOM(I,J)=R*(GXM-GIM)+GIM
      NN=NN+1
      AL1(J)=(TAB/NP1(J))*PRT
      IF(NN.GT.NH1(J)) GO TO 300
      DH(I,J)=(AL1(J)/NH1(J))*NN
      GO TO 210
 300  NXP=NH1(J)+NP1(J)
      IF(NN.GT.NXP) GO TO 400
      DH(I,J)=AL1(J)
      GO TO 210
 400  DH(I,J)=AL1(J)-(AL1(J)/NH1(J))*(NN-(NH1(J)+NP1(J)))
      GO TO 210
 811  IF(IWORK(I,J).EQ.0) GO TO 210
      R=GGUBFS(DSEED)
      AOM(I,J)=R*(GXM-GIM)+GIM
      MM=MM+1
      AL2(J)=(TAB/NP2(J))*PRT
      IF(MM.GT.NH2(J)) GO TO 301
      DH(I,J)=(AL2(J)/NH2(J))*MM
      GO TO 210
 301  MX=NH2(J)+NP2(J)
      IF(MM.GT.MX) GO TO 401
      DH(I,J)=AL2(J)
      GO TO 210
 401  DH(I,J)=AL2(J)-(AL2(J)/NH2(J))*(MM-NH2(J)-NP2(J))
 210  CONTINUE
      IF(M1.EQ.1) GO TO 405
      IF(J.EQ.1) GO TO 110
      N=J/M1
      K=M1*N+1
      IF(J.EQ.K) GO TO 405
      GO TO 110
 405  PRT=PRT+PRT*PRI
 110  CONTINUE
      DO 549 J=1,NOYR
      DO 649 I=1,365
      L=I
      M=J
      IF(I.EQ.1.AND.J.EQ.1) GO TO 649
      IF(IWIND(I,J).EQ.0) GO TO 249
      GO TO 649
 249  IF(I.EQ.1) GO TO 149
```

```
           GO TO 749
     149   L=366
           M=J-1
     749   AOM(L-1,M)=GXM
     649   CONTINUE
     549   CONTINUE
           DO 606 J=1,NOYR
           DO 505 I=1,365
           L=I
           M=J
           IF(I.EQ.365) GO TO 16
           GO TO 17
      16   L=0
           IF(J.NE.NOYR) M=J+1
      17   IF(IWORK(I,J).EQ.0.AND.IWORK(L+1,M).EQ.1) GO TO 707
           GO TO 505
     707   AOM(L+1,M)=GXM
     505   CONTINUE
     606   CONTINUE
           PRT=PRT1
           DO 410 J=1,NOYR
           DO 510 I=1,365
           GRAIN(I,J)=0.0
           FGRN(I,J)=0.0
C          THE FOLLOWING TWO STATEMENTS DEFINE  THE HARVESTING
C          SEASONS PER YEAR.
           IF(I.GT.IF1.AND.I.LT.IL1) GO TO 310
           IF(I.GT.IF2.AND.I.LT.IL2) GO TO 310
           GO TO 510
     310   CONTINUE
           IF(IWORK(I,J).EQ.0) GO TO 510
           L=I
           M=J
           IF(I.EQ.365) GO TO 15
           GO TO 25
      15   L=0
           IF(J.NE.NOYR) M=J+1
      25   CONTINUE
           KF=1
      26   CONTINUE
           LL=L+KF
           IF(LL.GT.365) GO TO 700
           GO TO 800
     700   LL =(LL-365)
           IF(M.NE.NOYR) M=M+1
     800   IF(ISUN(I,J).EQ.0.AND.ISUN(LL,M).EQ.0) GO TO 508
           IF(ISUN(I,J).EQ.1.AND.ISUN(LL,M).EQ.0) GO TO 508
           FGRN(I,J)=DH(I,J)
           GO TO 510
     508   IF(KF.EQ.KFD) GO TO 509
           KF=KF+1
           GO TO 26
     509   IF(DH(I,J).LT.TDD) GO TO 970
           GRAIN(I,J)=DH(I,J)-TDD
           GO TO 510
     970   GRAIN(I,J)=0.0
     510   CONTINUE
     410   CONTINUE
```

```
      RETURN
      END
C
C     ************************************************************
      SUBROUTINE FHGRN(NOYR,TDD,FM,FMCG)
C     THIS PART OF THE PROGRAM CALCULATES THE FLOW OF PARTIALLY
C     DRIED GRAIN FROM FARMERS' HOUSE TO THE PLANT
      COMMON /BB/TA(365,15),RA(365,15)
      COMMON /HH/ISUN(365,15)
      COMMON /OO/FGRN(365,15)
      COMMON /PP/FGRNP(365,15)
      COMMON /SS/AOM(365,15)
      DIMENSION FMCG(365,15)
      DO 300 J=1,NOYR
      DO 200 I=1,365
      FGRNP(I,J)=0.0
      FMCG(I,J)=0.0
      OM=AOM(I,J)
      OM1=OM
      IF(FGRN(I,J).GT.0.0) GO TO 111
      GO TO 200
  111 TA1=TA(I,J)
      CALL SSLG(TA1,OM,SSD7)
      ID=IFIX(SSD7)
      N=0
   40 N=N+1
      L=I
      M=J
      K=366-N
      IF(I.EQ.K) GO TO 15
      GO TO 25
   15 L=0
      IF(J.NE.NOYR) M=J+1
   25 IF(ISUN(L+N,M).EQ.0) GO TO 240
      TA2=TA(L+N,M)
      RA2=RA(L+N,M)
      CALL DBSR(TA2,RA2,OM1,FMC)
      IF(FMC.LE.FM) GO TO 200
      CALL SSLG(TA2,FMC,SSD9)
      LD2=IFIX(SSD9)
      ID=N+LD2
      OM1=FMC
      GO TO 40
  240 IF(N.GE.ID) GO TO 113
      GO TO 40
  113 IF(FGRN(I,J).LT.TDD) GO TO 114
      FGRNP(L+N,M)=FGRN(I,J)-TDD
      FMCG(L+N,M)=OM1
      GO TO 200
  114 FGRNP(L+N,M)=0.0
  200 CONTINUE
  300 CONTINUE
      RETURN
      END
C
C     ************************************************************
      SUBROUTINE GLOSS(NOYR,PI,P4,P5,DP,WR,GIM,GXM,FM,TA,GRAIN,
     *DGRAIN,SWC,DDR)
```

```
C     THIS SUBPROGRAM CALCULATES THE AMOUNT OF GRAIN LOSS DUE
C     TO INADEQUATE DRYING CAPACITY OF THE DRYING PLANT
      COMMON /SS/AOM(365,15)
      COMMON /TT/PLO(365,15),GLO(365,15)
      DIMENSION XLO(365,15),ALO(365,15),GRAIN(365,15)
     *,GRN(365,15),TA(365,15),DGRAIN(365,15)
      DO 150 J=1,NOYR
      DO 250 I=1,365
      XLO(I,J)=0.0
      ALO(I,J)=0.0
      PLO(I,J)=0.0
      GLO(I,J)=0.0
      GRN(I,J)=GRAIN(I,J)
 250  CONTINUE
 150  CONTINUE
      PP=P5
      P6=P4
      DO 200 J=1,NOYR
      DO 300 I=1,365
      IF(GRN(I,J).GT.0.0) GO TO 111
      OM=(GIM+GXM)/2
      GO TO 122
 111  OM=AOM(I,J)
 122  DDR=DR*WR
      IF(GRN(I,J).GE.DDR) GO TO 205
      DGRAIN(I,J)=GRN(I,J)
      GO TO 300
 205  DGRAIN(I,J)=DDR
      ALO(I,J)=GRAIN(I,J)-DDR
      IF(ALO(I,J).GT.0.0) GO TO 100
      GO TO 300
 100  CONTINUE
      TA1=TA(I,J)
      CALL SSLG(TA1,OM,SSD1)
      LD=IFIX(SSD1)
      XL=SSD1-LD
      IF(XL.GE.0.5) LD=LD+1
      IF(LD.GE.1) GO TO 400
      PLO(I,J)=ALO(I,J)*(P4+((P5-P4)/(GXM-FM))*(GXM-OM))
      GLO(I,J)=ALO(I,J)
      GO TO 300
 400  CONTINUE
      N=0
  40  N=N+1
      L=I
      M=J
      K=366-N
      IF(I.EQ.K) GO TO 15
      GO TO 25
  15  L=0
      IF(J.NE.NOYR) M=J+1
  25  IF(GRN(L+N,M).LT.DDR) GO TO 50
      IF(N.GT.LD) GO TO 20
      GO TO 40
  50  IF(N.GT.LD) GO TO 20
      XT=(DDR-GRN(L+N,M))
      IF(ALO(I,J).GT.XT) GO TO 10
      GRN(L+N,M)=GRAIN(L+N,M)+ALO(I,J)
```

```
      GO TO 300
   10 ALO(I,J)=ALO(I,J)-XT
      GRN(L+N,M)=GRAIN(L+N,M)+XT
      GO TO 40
   20 PLO(L+N,M)=ALO(I,J)*(P4+((P5-P4)/(GXM-FM))*(GXM-OM))
      XLO(L+N,M)=ALO(I,J)
  300 CONTINUE
      P4=P4+PI
      P5=P5+PI
  200 CONTINUE
      DO 125 J=1,NOYR
      DO 425 I=1,365
      GLO(I,J)=GLO(I,J)+XLO(I,J)
      IF(DGRAIN(I,J).GT.0.0.AND.AOM(I,J).EQ.0.0) GO TO 104
      GO TO 425
  104 AOM(I,J)=(GIM+GXM)/2
  425 CONTINUE
  125 CONTINUE
      P4=P6
      P5=PP
C     THIS PORTION OF THE PROGRAM CALCULATES THE CAPACITY OF
C     THE STORAGE BIN FOR WET GRAIN.
      SWC=0.0
      DO 225 J=1,NOYR
      DO 325 I=1,365
      L=I
      M=J
      IF(I.EQ.365) GO TO 35
      GO TO 45
   35 L=0
      IF(J.NE.NOYR) M=J+1
   45 SWC1=AMAX1(GRAIN(I,M),GRAIN(L+1,M))
      SWC=AMAX1(SWC,SWC1)
  325 CONTINUE
  225 CONTINUE
      RETURN
      END
C
C     ****************************************************************
      SUBROUTINE SSLG(TA,OM1,SSD)
C     THE SUBROUTINE FOR SAFE STORAGE LIFE(DAYS) OF HARVESTED
C     GRAIN.
      DOUBLE PRECISION A,B,C,D,E
      DATA ST/3.0/
      A=379.23D10
      B=-6.6581
      C=-2.0393
      D=OM1**B
      E=(TA+ST)**C
      SSD=(A*D*E)
      RETURN
      END
C
C     ****************************************************************
      SUBROUTINE ECOST(TA1,RA1,DR,TD,TH,DG,DG1,P1,OM,FM,
     *Q1,C,CEDD,A)
C     THIS PROGRAM CALCULATES THE COST OF ENERGY FOR DRYING
C     THE PARAMETERS RELATED TO THE AMBIENT AND HEATED AIR
```

```
      DOUBLE PRECISION PA,B2,C,DF1,Y
      DATA CPA/1.0/,CPV/1.88/,PA/101283.98/
      DATA RE/0.8/
C     THE PARAMETERS RELATED TO DRYER
      DATA X/0.7/,EF/0.60/
C     THE CONSTANTS RELATED TO THE GRAIN
      DATA B/51.16/,C/0.000019187/,AN/2.4451/
      DATA B2/2.323/,B3/1.026/,B4/2.9462/,C2/17.78/,C3/0.21733/
C     THE VALUE OF DF IS AN ARBRITRARY NUMBER NECESSARY TO
C     INITIALIZE FOR ITERATION BETWEEN LINE NUMBER 200 TO
C     300(LOOP). CHECK CAREFULLY FOR SETTING THE VALUE OF DF.
      DF=15.0
      A=DR/X
      RD=SQRT(A/3.1428)
      CALL SATVP(TA1,PSA)
      HR=((0.6219)*RA1*PSA)/(PA-RA1*PSA)
      CALL SATVP(TH,PSH)
      RH=(HR*PA)/((HR+0.6219)*PSH)
      CALL EQUMST(TH,RH,EM)
      VL=B2*(1090-B3*(TH+C2))*(1+B4*EXP(-C3*OM))
      TE=-(B+(ALOG(1-RE))/(C*OM**AN))
      CALL DRCNST(TH,DK)
      H=0.693147/DK
      PV=RH*PSH
      VS=(287*(TH+273.15))/(PA-PV)
      RMX=(FM-EM)/(OM-EM)
      RM=ABS(RMX)
      Y=EXP(-TD*0.693147/H)
 200  CONTINUE
      DF1=1.442695*DLOG((EXP(RM*DF*0.693147))/Y+1-1/Y)
      DFF=(DF-DF1)
      IF(DFF.LE.0.0001) GO TO 300
      DF=DF1
      GO TO 200
 300  SM=(X*DG*A*VL*(OM-EM)/100)/(CPA*DF1*H*(TE-TE))
      Q=(SM*VS)/(3600.0*A)
C     CALCULATE THE COST OF GRAIN DRYING
      CD1=((TH-TA1)*SM*TD*(CPA+HR*CPV)*P1)/(Q1*EF*DE)
      CEDD=CD1*DG1
      RETURN
      END
C
C     ***********************************************************
      SUBROUTINE SATVP(T,PS)
C     SUBROUTINE FOR CALCULATION OF SATURATED VAPOR PRESSURE AT
C     DIFFERENT TEMPERATURES
      DOUBLE PRECISION P1,P2
      P1=-27405.526+(97.5413*(T+273.16))-(0.146244*(T+273.16)**2)
     $+((0.12558D-3)*(T+273.16)**3)-((0.485D-7)*(T+273.16)**4)
      P2=(4.34903*(T+273.16))-((0.39381D-2)*(T+273.16)**2)
      PS=DEXP((P1/P2)+16.91)
      RETURN
      END
C
C     ***********************************************************
      SUBROUTINE EQUMST(TH,R,EM)
C     SUBROUTINE FOR CALCULATION OF EQUILIBRIUM MOISTURE CONTENT
C     OF GRAIN
```

```
      DOUBLE PRECISION C
      DATA B/51.16/,C/0.000019187/,AN/2.4451/
      EM=(ALOG(1-R)/(-C*(TH+B)))**(1/AN)
      RETURN
      END
C
C     ***********************************************************
      SUBROUTINE DRCNST(TH,DK)
C     SUBROUTINE FOR CALCULATION OF DRYING CONSTANT
      DOUBLE PRECISION B1,C1
      DATA B1/136485.6/,C1/4811.671/
      DK=B1*DEXP(-C1/(TH+273.15))
      RETURN
      END
C
C     ***********************************************************
      SUBROUTINE DESR(TA,RA,OMC,FMS)
C     SUBROUTINE FOR CALCULATION OF MOISTURE CONTENT OF GRAIN
C     AFTER SUN DRYING
      DOUBLE PRECISION PA
      DATA TF/0.90/,DSH/7.0/,TC/10.0/,PA/101283.98/
      ESH=TF*DSH
      TS=TA+TC
      CALL SATVP(TA,PSA)
      HR=((0.6219)*RA*PSA)/(PA-RA*PSA)
      CALL SATVP(TS,PSH1)
      RH1=(HR*PA)/((HR+0.6219)*PSH1)
      CALL DRCNST(TS,DK1)
      RM1=EXP(-ESH*DK1)
      CALL EQUMST(TS,RH1,EM1)
      FMS=EM1+RM1*(OMC-EM1)
      RETURN
      END
C
C     ***********************************************************
      SUBROUTINE CFAN(P2,TD,Q,VG,COFO)
C     THIS SUBROUTINE CALCULATES THE COST OF OPERATING FAN FOR
C     MOVING AIR THROUGH GRAIN DURING DRYING.
      DATA A/3652.62/,B/1.1867/,E1/0.85/
      PD=A*(Q**B)
      PF=(Q*PD)/1000
      CF=(PF*TD*P2)/E1
      COFO=CF*VG
      RETURN
      END
C
C     ***********************************************************
      SUBROUTINE CEG(NOYR,TD,M2,PIN1,EH1,EH2,P2,DDG,DWG,DR,
     *OM,FM,AMO,PE1,PE3)
C     CALCULATE THE COST OF ELEVATING GRAIN DURING DRYING.
      COMMON /DD/DGRAIN(365,15),DLOS(365,15)
      COMMON /FF/FMCG(365,15),DFGRN(365,15),COSM(365,15)
      DIMENSION PE4(365,15),CEC1(365,15),
     *CEC2(365,15),CEC3(365,15),CEC4(365,15),CEC5(365,15),
     *GEX(365,15)
      DATA E1/0.85/
      PO=P2
      PE1=(DR*DWG*EH1)/(367085*TD)
```

```
      PE2=(DR*DDG*EH2)/(367085*TD)
      DG1=DWG-((DWG-DDG)/(OM-FM))*(OM-AMO)
      PE3=(DR*DG1*EH2)/(367085*TD)
      DO 200 J=1,NOYR
      DO 300 I=1,365
      IF(FMCG(I,J).EQ.0.0) GO TO 300
      DG2=DWG-((DWG-DDG)/(OM-FM))*(OM-FMCG(I,J))
      PE4(I,J)=(DR*DG2*EH1)/(367085*TD)
  300 CONTINUE
  200 CONTINUE
      DO 250 J=1,NOYR
      DO 350 I=1,365
      CEC1(I,J)=0.0
      CEC2(I,J)=0.0
      CEC3(I,J)=0.0
      CEC4(I,J)=0.0
      CEC5(I,J)=0.0
      IF(DGRAIN(I,J).EQ.0.0) GO TO 201
      CEC1(I,J)=(PE1*TD*(DGRAIN(I,J)/DR)*P2)/E1
      CEC3(I,J)=(PE3*TD*(DGRAIN(I,J)/DR)*P2)/E1
  201 IF(DFGRN(I,J).EQ.0.0) GO TO 202
      CEC2(I,J)=(PE4(I,J)*TD*(DFGRN(I,J)/DR)*P2)/E1
      CEC4(I,J)=(PE2*TD*(DFGRN(I,J)/DR)*P2)/E1
  202 GEX(I,J)=DGRAIN(I,J)-DLOS(I,J)
      IF(GEX(I,J).EQ.0.0) GO TO 350
      CEC5(I,J)=(PE2*TD*(GEX(I,J)/DR)*P2)/E1
  350 CONTINUE
      IF(M2.EQ.1) GO TO 551
      N2=J/M2
      K2=M2*N2+1
      IF(J.EQ.1) GO TO 250
      IF(J.EQ.K2) GO TO 551
      GO TO 250
  551 P2=P2+P2*PIN1
  250 CONTINUE
      P2=P0
      DO 450 J=1,NOYR
      DO 550 I=1,365
      COSM(I,J)=CEC1(I,J)+CEC2(I,J)+CEC3(I,J)+CEC4(I,J)
     *+CEC5(I,J)
  550 CONTINUE
  450 CONTINUE
      RETURN
      END
C
C     ***********************************************************
C     THIS IS A FUNCTION SUBPROGRAM FOR GENERATION
C     OF RANDOM NUMBER
C     GGUBFS - RESULTANT DEVIATE.
C     DSEED - INPUT/OUTPUT DOUBLE PRECISION VARIABLE
C     ASSIGNED AN INTEGER VALUE IN THE EXCLUSIVE RANGE
C     (1.D0, 2147483647.D0).
C     DSEED IS REPLACED BY A NEW VALUE TO BE USED IN A
C     SEQUENTIAL CALL.
      REAL FUNCTION GGUBFS (DSEED)
      DOUBLE PRECISION  DSEED
      DOUBLE PRECISION  D2P31M,D2P31
C     D2P31M = (2**31)-1
```

```
C     D2P31 = (2**31)(OR AN ADJUSTED VALUE)
      DATA D2P31M/2147483647.D0/
      DATA D2P31/2147483648.D0/
      DSEED = DMOD(16807.D0*DSEED,D2P31M)
      GGUBFS = DSEED / D2P31
      RETURN
      END
C
C     ***********************************************************
      SUBROUTINE CSD1(NOYR,TD,TH,M3,Q1,PIN,PIX,P3,P4,P5,PM,GXM,
     *DDR,DR,DDG,PI,P1,AMO,A1)
C     THIS SUBROUTINE CALCULATES THE AMOUNT, COST AND LOSS OF
C     PARTIALLY DRIED GRAIN DURING SUN DRYING. THE DRYING
C     SEQUENCE IS : 1ST DRY THE GRAIN(PARTIALLY DRIED) BY
C     NATURAL SUN, IF SUN IS NOT AVAILABLE DRY BY THE PLANT.
      COMMON /BB/TA(365,15),RA(365,15)
      COMMON /DD/DGRAIN(365,15),DLOS(365,15)
      COMMON /EE/COST(365,15),DCOST(365,15),PLNT(365,15),
     *DPLS(365,15),CSL(365,15),QFS(365,15)
      COMMON /HH/ISUN(365,15)
      DIMENSION SGRAIN(365,15),SLO(365,15),
     *SGRN(365,15),GRNN(365,15)
      DATA X1/0.02/,A2/200.0/,DSH/7.0/
      AL=A1/A2
      NL=IFIX(A1/A2)
      XLL=(AL-NL)
      IF(XLL.GE.0.5) NL=NL+1
      DO 90 J=1,NOYR
      DO 92 I=1,365
      SLO(I,J)=0.0
      COST(I,J)=0.0
      QFS(I,J)=0.0
      SGRN(I,J)=0.0
      CSL(I,J)=0.0
      DCOST(I,J)=0.0
      PLNT(I,J)=DGRAIN(I,J)
      DPLS(I,J)=0.0
      DLOS(I,J)=0.0
      GRNN(I,J)=DGRAIN(I,J)
   92 CONTINUE
   90 CONTINUE
      PO=P1
      PM=P4
      PN=P5
      PZ=P3
      DO 300 J=1,NOYR
      NW=0
      SCOST =NL*P3*DSH
      DO 200 I=1,365
      OM=GXM
      VGS=A1*X1
      M=J
      L=I
      NZ=I
      IF(NW.GT.I) NZ=NW
      SGRAIN(I,J)=GRNN(I,J)+SLO(I,J)
      IF(SGRAIN(I,J).EQ.0.0) GO TO 200
      IF(SGRAIN(I,J).LT.0.0) GO TO 222
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```
      IF(AMO.LE.FM) GO TO 200
      DG2=SGRAIN(I,J)
      AM1=AMO
      AMS=AM1
      AMC=AMS
      TA1=TA(I,J)
      CALL SSLG(TA1,AM1,SSD6)
      LD=IFIX(SSD6)
      XLL1=SSD6-LD
      IF(XLL1.GE.0.5) LD=LD+1
      IF(NZ.EQ.365) GO TO 101
      GO TO 801
101   NZ=0
      IF(J.NE.NOYR) M=J+1
801   N1=NZ+1
      I2=0
      K0=0
      K1=0
      K3=0
      K4=0
      LD2=LD
      Y=DG2-VGS
302   DO 250 N=N1,365
      IF(L.EQ.365) GO TO 14
      GO TO 15
 14   L=0
      IF(M.LT.NOYR) M=M+1
 15   CONTINUE
      TA3=TA(N,M)
      RA3=RA(N,M)
      IF(ISUN(N,M).EQ.0) GO TO 240
      IF(Y.GT.0.0.AND.Y.LE.VGS) GO TO 100
      IF(Y.GT.VGS) GO TO 150
      IF(SGRN(N,M).EQ.VGS) GO TO 240
      CALL DBSR(TA3,RA3,AM1,AMC)
      SGRN(N,M)=VGS
      COST(N,M)=SCOST
      SLO(L+1,M)=Y
      IF(AMC.LE.FM) GO TO 202
      K1=K1+1
      GO TO 613
100   IF(SGRN(N,M).EQ.VGS) GO TO 240
      CALL DBSR(TA3,RA3,AM1,AMC)
      SGRN(N,M)=VGS
      COST(N,M)=SCOST
      SLO(L+1,M)=Y
      IF(AMC.LE.FM) GO TO 202
900   K1=K1+1
      K3=K0+K1
      IF(K3.GE.LD) GO TO 513
      GO TO 613
150   IF(SGRN(N,M).EQ.VGS) GO TO 240
      CALL DBSR(TA3,RA3,AM1,AMC)
      SGRN(N,M)=VGS
      COST(N,M)=SCOST
      IF(AMC.LE.FM) GO TO 910
      GO TO 900
910   Y=Y-VGS
```

```
      AMC=AMS
      GO TO 900
 613  CALL SSLG(TA3,AMC,SSD8)
      LD1=IFIX(SSD8)
      SLL2=SSD8-LD1
      IF(XLL2.GE.0.5) LD1=LD1+1
      AM1=AMC
      IP=1
      K4=0
      IF(DGRAIN(L+1,M).LE.0.0) GO TO 250
      DG4=DGRAIN(L+1,M)
      TA4=TA(L+1,M)
      CALL SSLG(TA4,AMS,SSDA)
      LD2=IFIX(SSDA)
      XLL3=SSDA-LD2
      IF(XLL3.GE.0.5) LD2=LD2+1
      IF(K3.GE.LD2) GO TO 611
      GO TO 250
 611  IF(PLNT(N,M).LT.DDR) GO TO 112
      CSL(N,M)=DG4*(P4+((P5-P4)/(OM-FM))*(OM-AMS))
      DLOS(N,M)=DG4
      GRNN(L+1,M)=0.0
      GO TO 250
 112  EXS=(DDR-PLNT(N,M))
      IF(DG4.GT.EXS) GO TO 702
      CALL ECOST(TA3,RA3,DR,TD,TH,DDG,DG4,P1,AMS,FM,Q1,
     *QBY,COSTY,A)
      DCOST(N,M)=COSTY
      PLNT(N,M)=PLNT(N,M)+DG4
      DPLS(N,M)=DG4
      QFS(N,M)=QBY
      GRNN(L+1,M)=0.0
      GO TO 250
 702  CSL(N,M)=(DG4-EXS)*(P4+((P5-P4)/(OM-FM))*(OM-AMS))
      DLOS(N,M)=(DG4-EXS)
      CALL ECOST(TA3,RA3,DR,TD,TH,DDG,EXS,P1,AMS,FM,Q1,
     *QBZ,COSTZ,A)
      PLNT(N,M)=PLNT(N,M)+EXS
      DPLS(N,M)=EXS
      DCOST(N,M)=COSTZ
      QFS(N,M)=QBZ
      GRNN(L+1,M)=0.0
      GO TO 250
 213  IF(PLNT(N,M).LT.DDR) GO TO 714
      CSL(N,M)=VGS*(P4+((P5-P4)/(OM-FM))*(OM-AM1))
      DLOS(N,M)=VGS
      SLO(L+1,M)=0.0
      GO TO 202
 513  IF(PLNT(N,N).LT.DDR) GO TO 614
      CSL(N,M)=Y*(P4+((P5-P4)/(OM-FM))*(OM-AMC))
      DLOS(N,M)=Y
      SLO(L+1,M)=0.0
      Y=0.0
      GO TO 613
 240  CONTINUE
      KO=KO+1
      IF(IP.EQ.1) GO TO 242
      IF(KO.GE.LD) GO TO 113
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      IF(N.EQ.I.AND.M.EQ.J+1)  GO TO 113
      XL=DG2
      IF(N.EQ.365) GO TO 241
      GO TO 250
242   K4=K4+1
      K5=K4+K3
      IF(K5.GE.LD) GO TO 513
      IF(K4.GE.LD2) GO TO 611
      IF(N.EQ.I.AND.M.EQ.J+1) GO TO 213
      XL=VGS
      IF(N.EQ.365) GO TO 241
      GO TO 250
113   IF(PLNT(N,M).LT.DDR) GO TO 924
      CSL(N,M)=DG2*(P4+((P5-P4)/(OM-FM))*(OM-AM1))
      DLOS(N,M)=DG2
      GO TO 202
714   EXT=(DDR-PLNT(N,M))
      IF(VGS.GT.EXT) GO TO 715
      CALL ECOST(TA3,RA3,DR,TD,TH,DDG,VGS,P1,AM1,FM,Q1,
     *QB6,COST6,A)
      PLNT(N,M)=PLNT(N,M)+VGS
      DCOST(N,M)=COST6
      DPLS(N,M)=VGS
      QFS(N,M)=QB6
      SLO(L+1,M)=0.0
      GO TO 202
715   CSL(N,M)=(VGS-EXT)*(P4+((P5-P4)/(OM-FM))*(OM-AM1))
      DLOS(N,M)=(VGS-EXT)
      CALL ECOST(TA3,RA3,DR,TD,TH,DDG,EXT,P1,AM1,FM,Q1,
     *QB7,COST7,A)
      PLNT(N,M)=PLNT(N,M)+EXT
      DPLS(N,M)=EXT
      DCOST(N,M)=COST7
      QFS(N,M)=QB7
      SLO(L+1,M)=0.0
      GO TO 202
614   EXM=(DDR-PLNT(N,M))
      IF(Y.GT.EXM) GO TO 615
      CALL ECOST(TA3,RA3,DR,TD,TH,DDG,Y,P1,AMC,FM,Q1,
     *QB8,COST8,A)
      QFS(N,M)=QB8
      PLNT(N,M)=PLNT(N,M)+Y
      DPLS(N,M)=Y
      DCOST(N,M)=COST8
      SLO(L+1,M)=0.0
      Y=0.0
      GO TO 613
615   CSL(N,M)=(Y-EXM)*(P4+((P5-P4)/(OM-FM))*(OM-AMC))
      DLOS(N,M)=(Y-EXM)
      CALL ECOST(TA3,RA3,DR,TD,TH,DDG,EXM,P1,AMC,FM,Q1,
     *QB9,COST9,A)
      DCOST(N,M)=COST9
      QFS(N,M)=QB9
      PLNT(N,M)=PLNT(N,M)+EXM
      DPLS(N,M)=EXM
      SLO(L+1,M)=0.0
      Y=0.0
      GO TO 613
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 924  EXG=(DDR-PLNT(N,M))
      IF(DG2.GT.EXG) GO TO 925
      CALL ECOST(TA3,RA3,DR,TD,TH,DDG,DG2,P1,AM1,FM,Q1,
     *QB10,COST10,A)
      DCOST(N,M)=COST10
      PLNT(N,M)=PLNT(N,M)+DG2
      DPLS(N,M)=DG2
      QFS(N,M)=QB10
      GO TO 202
 925  CSL(N,M)=(DG2-EXG)*(P4+((P5-P4)/(OM-FM))*(OM-AM1))
      DLCS(N,M)=(DG2-EXG)
      CALL ECOST(TA3,RA3,DR,TD,TH,DDG,EXG,P1,AM1,FM,Q1,
     *QB11,COST11,A)
      DCOST(N,M)=COST11
      QFS(N,M)=QB11
      PLNT(N,M)=PLNT(N,M)+EXG
      DPLS(N,M)=EXG
      GO TO 202
 250  CONTINUE
      GO TO 200
C     LOOK FOR THE SUNNY DAY TO THE FOLLOWING YEAR
 241  N1=1
      M=M+1
      IF(M.GT.NOYR) GO TO 207
      GO TO 250
 207  CSL(N,M-1)=XL*(P4+((P5-P4)/(OM-FM))*(OM-AM1))
      DLOS(N,M-1)=XL
      GO TO 300
 222  IF(L.EQ.365) GO TO 11
      GO TO 12
  11  L=0
      IF(M.NE.NOYR) M=M+1
  12  SLO(L+1,M)=SGRAIN(I,J)
      GO TO 200
 202  NW=N
 200  CONTINUE
      P3=P3+PIX
      P5=P5+PI
      P4=P4+PI
      NX=J/M3
      IF(M3.EQ.1) GO TO 299
      KX=M3*NX+1
      IF(J.EQ.1) GO TO 300
      IF(J.EQ.KX) GO TO 299
      GO TO 300
 299  P1=P1+P1*PIN
 300  CONTINUE
      P4=PM
      P5=PN
      P1=PO
      P3=PZ
      RETURN
      END
C
C     ****************************************************************
      SUBROUTINE CSD2(NOYR,TD,TH,M3,Q1,PIN,PIX,P3,P4,P5,FM,GXM,
     *DDR,DR,DDG,PI,P1,AMO,A1)
C     THIS SUBROUTINE CALCULATES THE AMOUNT, COST AND LOSS OF
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C     PARTIALLY DRIED GRAIN DURING DRYING. THE SEQUENCE IS :
C     1ST DRY THE GRAIN(PARTIALLY DRIED) BY THE PLANT, IF PLANT
C     IS NOT AVAILABLE DRY BY SUN.
      COMMON /BB/TA(365,15),RA(365,15)
      COMMON /DD/DGRAIN(365,15),DLOS(365,15)
      COMMON /EE/COST(365,15),DCOST(365,15),PLNT(365,15),
     *DPLS(365,15),CSL(365,15),QFS(365,15)
      COMMON /HH/ISUN(365,15)
      DIMENSION DGRAN(365,15),SGRN(365,15),GRNN(365,15)
      DATA X1/0.02/,A2/200.0/,DSH/7.0/
      AL=A1/A2
      NL=IFIX(A1/A2)
      XLL=(AL-NL)
      IF(XLL.GE.0.5) NL=NL+1
      DO 90 J=1,NOYR
      DO 92 I=1,365
      COST(I,J)=0.0
      QFS(I,J)=0.0
      SGRN(I,J)=0.0
      CSL(I,J)=0.0
      DCOST(I,J)=0.0
      PLNT(I,J)=DGRAIN(I,J)
      DPLS(I,J)=0.0
      DLOS(I,J)=0.0
      DGRAN(I,J)=DGRAIN(I,J)
      GRNN(I,J)=0.0
   92 CONTINUE
   90 CONTINUE
      PO=P1
      PM=P4
      PN=P5
      PZ=P3
      OM=GXM
      VGS=A1*X1
      DO 300 J=1,NOYR
      SCOST=NL*P3*DSH
      DO 200 I=1,365
      IF(DGRAIN(I,J).GT.0.0) GO TO 111
      GO TO 200
  111 IF(AMO.LE.PM) GO TO 200
      TA1=TA(I,J)
      AM1=AMO
      AMS=AM1
      CALL SSLG(TA1,AM1,SSD6)
      LD=IFIX(SSD6)
      XLL=SSD6-LD
      IF(XLL.GE.0.5) LD=LD+1
      N=0
   40 N=N+1
      L=I
      M=J
      K=366-N
      IF(I.EQ.K) GO TO 15
      GO TO 25
   15 L=0
      IF(J.NE.NOYR) M=J+1
   25 TA3=TA(L+N,M)
      RA3=RA(L+N,M)
```

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      DG4=DGRAN(I,J)
      IF(PLNT(L+N,M).LT.DDR) GO TO 113
      IF(N.GT.LD) GO TO 250
      GO TO 40
113   IF(N.GT.LD) GO TO 250
      EXS=(DDR-PLNT(L+N,M))
      IF(DG4.GT.EXS) GO TO 702
      CALL ECOST(TA3,RA3,DR,TD,TH,DDG,DG4,P1,AMS,FM,Q1,
     *QBY,COSTY,A)
      DCOST(L+N,M)=COSTY
      PLNT(L+N,M)=PLNT(L+N,M)+DG4
      DPLS(L+N,M)=DG4
      QPS(L+N,M)=QBY
      GO TO 200
702   CALL ECOST(TA3,RA3,DR,TD,TH,DDG,EXS,P1,AMS,FM,Q1,
     *QBZ,COSTZ,A)
      PLNT(L+N,M)=PLNT(L+N,M)+EXS
      DPLS(L+N,M)=EXS
      DCOST(L+N,M)=COSTZ
      QPS(L+N,M)=QBZ
      DGRAN(I,J)=DGRAN(I,J)-EXS
      GO TO 40
250   IF(ISUN(L+N,M).EQ.0) GO TO 240
      TA2=TA(L+N,M)
      RA2=RA(L+N,M)
      IF(GRNN(L+N,M).GE.VGS) GO TO 240
      SPD=VGS-GRNN(L+N,M)
      IF(DGRAN(I,J).GT.SPD) GO TO 260
      CALL DBSR(TA2,RA2,AM1,AMC)
      SGRN(L+N,M)=DGRAN(I,J)
      COST(L+N,M)=SCOST
      IF(DGRAN(I,J).EQ.0.0) COST(L+N,M)=0.0
      GRNN(L+N,M)=DGRAN(I,J)
      IF(AMC.LE.FM) GO TO 200
      CALL SSLG(TA2,AMC,SSD8)
      LD2=IFIX(SSD8)
      XLL1=SSD8-LD2
      IF(XLL1.GE.0.5) LD2=LD2+1
      LD=N+LD2
      AM1=AMC
      AMS=AMC
      GO TO 40
260   DX=DGRAN(I,J)
      DGRAN(I,J)=DGRAN(I,J)-SPD
      CALL DBSR(TA2,RA2,AM1,AMC)
      SGRN(L+N,M)=SPD
      COST(L+N,M)=SCOST
      GRNN(L+N,M)=SPD
      IF(AMC.LE.FM) GO TO 241
      AM1=(AMC*SPD+AM1*DGRAN(I,J))/(SPD+DGRAN(I,J))
      AMS=AM1
      CALL SSLG(TA2,AMS,SSD9)
      LD3=IFIX(SSD9)
      XLL2=SSD9-LD3
      IF(XLL2.GE.0.5) LD3=LD3+1
      LD=N+LD3
      DGRAN(I,J)=DX
241   IF(N.GT.LD) GO TO 240
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      GO TO 40
240   CSL(L+N,M)=DGRAN(I,J)*(P4+((P5-P4)/(OM-FM))*(OM-AMS))
      DLOS(L+N,M)=DGRAN(I,J)
200   CONTINUE
      P3=P3+PIX
      P5=P5+PI
      P4=P4+PI
      NX=J/M3
      IF(M3.EQ.1)  GO TO  299
      KX=M3*NX+1
      IF(J.EQ.1)  GO TO  300
      IF(J.EQ.KX)  GO TO  299
      GO TO 300
299   P1=P1+P1*PIN
300   CONTINUE
      P4=PM
      P5=PN
      P1=PO
      P3=PZ
      RETURN
      END
```