

**MACHINERY SELECTION AND SCHEDULING MODEL
FOR VIRGINIA**

by

Huanbao Xiong

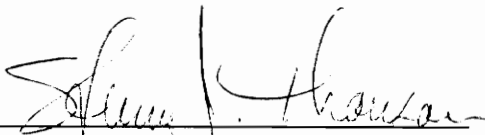
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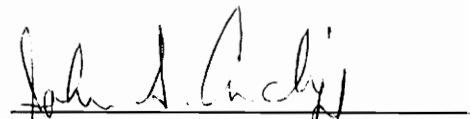
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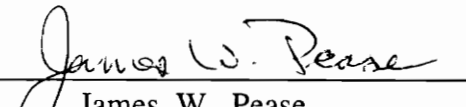
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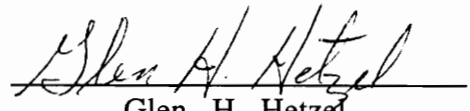
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(ABSTRACT)

A field machinery selection model originally developed by Dr. John C. Siemens for Illinois has been fully studied and adapted to Virginia agriculture. The modified version of this model is able to assist farm managers in selecting optimum machinery sets for multiple cropping production systems. The program was written in the C programming language to run on an IBM compatible personal computer. The program input information consists of a list of desired field operations with start date, acres, and hours per day for each operation. Other input includes crop yields, penalty dates for planting and harvesting, availability and cost of labor, and certain economic data such as crop and fuel prices and interest rates. Stored data files contain machine list prices and productivity values, work-day probabilities, and equation constants for computing machine costs. For different machinery sets or a specified set of machinery, the program schedules the field operations and computes the total machinery related costs including costs for the machines, labor,

and timeliness. Using an optimization process, the lowest cost machinery set is determined and the eight lowest cost sets found during the process are presented. For any of the eight lowest cost sets, or for a specific set of machinery, the output includes a list of the machinery with prices and annual use, the work schedule, the cost for each operation, and total machinery related costs.

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Chapter 1

Introduction

1.1 Background

Machinery management has increased in importance in today's farming operations because of its direct relation to the success of management in mixing land, labor and capital to return a satisfactory profit. If the American farmer is to continue to be successful, all available resources must be utilized to their fullest potential (Freeman and McGrann, 1990; Freeman and Whittaker, 1992).

The importance of machinery in the total farming operation is indicated by machinery costs in relation to the total costs. Typically, machinery costs overshadow all

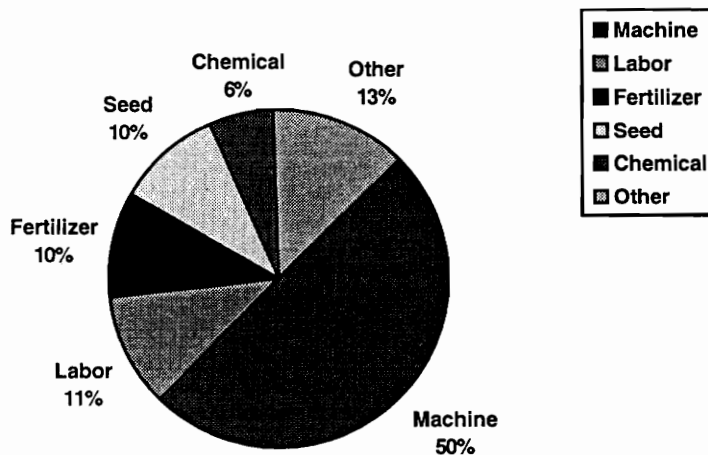


Figure 1.1 Machinery Costs as a Proportion of Total Annual Costs

other costs except land (Haffar and Khoury, 1992). Machinery cost often accounts for fifty percent of all annual costs (Fig. 1.1), and can run as high as \$200 per acre (\$500 per hectare) per year for intensive cropping systems on irrigated land (Hunt, 1983). It is not unusual to find that differences in profit from one farm to another are due solely to differences in how machinery are selected and managed (Whiston et al., 1981).

The problems of machinery management are varied in their nature. Following are some typical examples of the more important problems. In each case, a decision made could mean the difference between a profit or a loss.

- How much equipment should be owned ?
- What size equipment is needed ?
- How do you schedule the field operations using the current machinery set ?
- How often should you trade machinery ?
- Should you repair present machine or trade ?

Modern farming operations usually involve several different crops, with each one having its own tillage, planting and harvesting requirements. There can be quite a number of special tools by size and type for each field operation. But each machine purchased involves overhead costs - depreciation, taxes, housing, insurance and interest. These overhead costs, or fixed costs, can diminish profits rapidly.

Large scale equipment with large capacities can improve the yield of a farming operation by enabling a farm manager to schedule field operations within a range of most desirable working days. However, costs associated with large scale equipment may

override the benefit of an increase in yield (Short and Gitu, 1991). Conversely, inadequate equipment capacities can extend spring land preparation and planting times to the point that crop maturity may be delayed and yield may be decreased. Harvesting may therefore be postponed with a resulting delay or elimination of fall tillage operations. Current or future return may be adversely affected from such delay.

Modern farming is a business. Like any business, one must attempt to make a maximum return on the investment (Robb et al., 1990). Efficient selection and management of equipment for the farm should help achieve both short and long range financial goals.

Large machinery results in lower labor costs. Large tractors for example, furnish sufficient power to complete large acreage jobs quickly. But unless the tractor has a high annual use or the owner plans to own it for ten to twelve years or more, overhead, or fixed costs can exceed even the most expensive labor costs.

Smaller tractors cost less per hour than larger tractors. By having high annual use, the owner may be ready to trade in six to eight years instead of ten to twelve years. Smaller tractors have less capacity which, in turn, can cause delays in key field operations.

By carefully analyzing the work to be done in the available time, tractors can be selected to work with the correctly sized machines to complete important field operations on time. This timeliness factor makes proper machine size selection important (Audsley, 1984).

Size selection of machinery is based on a combination of expected performance and expected costs criteria. Capacity and capital costs increase with size. At the same time, performance improves, particularly with critical operations such as planting and harvesting. Delays in planting can reduce yields. Delays in harvesting can reduce both quantity and quality of production. These losses are called timeliness losses.

Figure 1.2 illustrates the interaction of machinery costs and timeliness costs to help determine the optimum size of a machine.

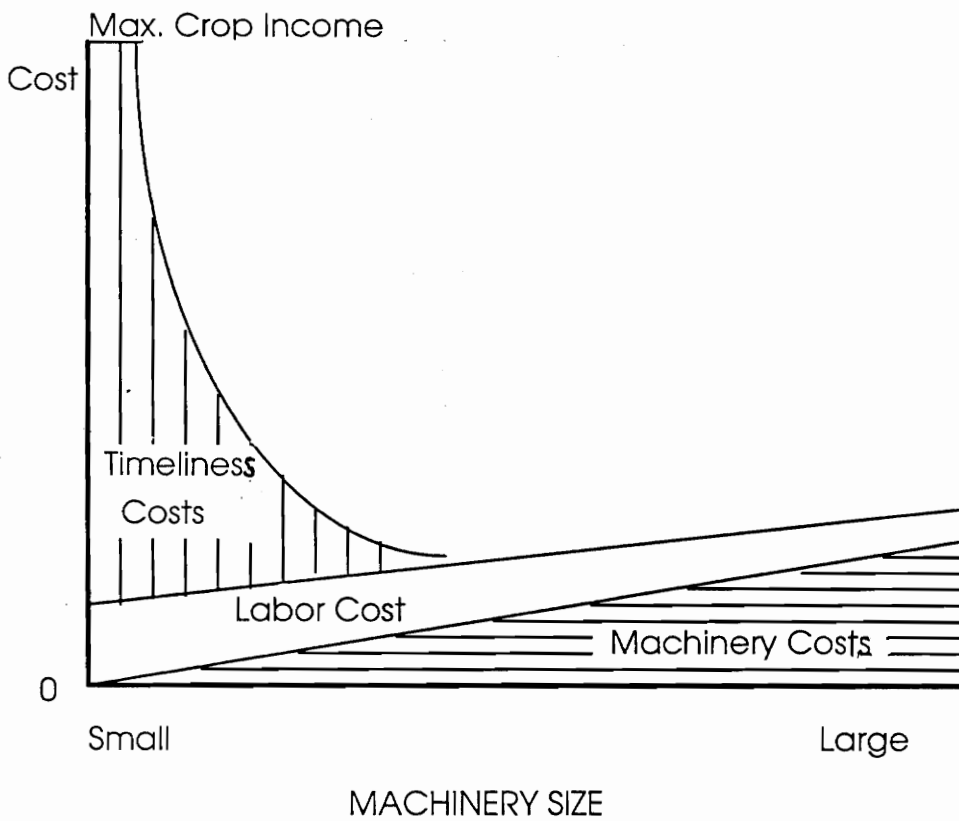


Figure 1.2 Costs Related to Machinery Size for a Specific Farm Size

1.2 Objectives

The objective of this research is to adapt a machinery selection program for Virginia agriculture. The Machinery Selection Program version 10 (Siemens et al., 1992) was chosen for this study. This program helps the farm managers select the optimum machinery complements to minimize the machinery related costs per acre based on the cropping system, size of the farm, labor availability and costs, and current economic situation. The program also schedules the field operations using the selected optimum machinery set for the farm manager. The program was developed for the farming systems of Illinois. Because different farming conditions exist between Illinois and Virginia, this program can not be used directly in Virginia unless modifications are made. This study will focus on the methodologies used in the program and modifications needed to adapt this program to a Virginia farming system. Specific tasks of this research include:

- 1) Running the program with several example farm data sets and analyzing the results to reveal methodologies used in the program.
- 2) Analyzing the structure of the program to identify relationships among the program modules and data files. This helps identify the necessary modifications to adapt this program for Virginia.
- 3) Modifying and running the program with data from a Virginia farm obtained by a farm management agent and analyzing the results.

Chapter 2

Literature Review

The management of agricultural machinery is an area that has received significant attention. Over the last twenty years, engineers and scientists have developed many computer simulation models that can be employed to analyze a complex farm situation. These computer simulation models can help farm managers make planning and/or management decisions in the selection and optimum utilization of machinery, labor, and other farm resources. A review of literature dealing with farm machinery selection reveals several approaches to the problem.

2.1 Problem Solving Models

The first approach can be labeled the “Problem Solving Models” which is based on budgeting procedures. This approach does not derive optimum machinery size or number for a given farm because it excludes the interrelationship between timeliness and yield. The main objective of this type of model is to assume completion of certain field operations before a given set of dates to minimize costs. No penalty is assumed if operations were not completed before a specific date. In this case, an adjustment in machinery size and /or number is made to eliminate the timeliness costs. However, no investigations are performed to determine if the saving in the timeliness costs are significant enough to justify the added ownership cost of the larger implements (Chen and McClendon, 1985,

Chen, 1987; Ozkan et al., 1990). The models developed in this approach can be used to serve as decision support systems for the farm manager and are simple and inexpensive to develop and use.

Chen and McClendon (1985) developed a model called DCMOD for the southeast region of the United States where double cropping soybeans and wheat is gaining in popularity among producers. In this system, wheat is planted in the fall after soybean harvest. Wheat is harvested in the spring followed by soybean planting. The model simulates the effects on economic return from the rate of planting and harvesting (equipment capacity), initial planting dates, and percentage of total farm acreage double cropped. In the authors' analysis, cropping seasons were independent with a full wheat acreage available for harvest in the spring, regardless of the actual fall planting acreage.

McClendon et al. (1987) developed a model called DCTEM. It was an improved version of DCMOD which considered the temporal nature of field operations. DCTEM allowed for interdependent years of field operations. Only the amount of wheat actually planted at the end of the year was available for harvest at the beginning of the next year. In DCMOD, a constant acreage of wheat was always available for harvest. The DCTEM model utilized a yield and maturity date calculation that was strictly a function of planting date with no consideration made to actual weather. A heuristic algorithm was used to relate rainfall frequency to excess or insufficient soil water conditions. The relative advantages and drawbacks of different machinery complements for three different size

production operations were evaluated. DCMOD and DCTEM were written and executed on a CYBER mainframe computer.

Allison et al. (1989) converted the original DCTEM model for use on PC computers. To predict yield and maturity date data reflecting the actual weather year, two crop growth simulation models were employed: SOYGRO Version 5.41 (Jones et al., 1988) and CERES - Wheat Version 2.0 (Ritchie and Otter, 1985). Both models are included in the IBSNAT (International Benchmarks Sites Network for Agrotechnology Transfer) project (IBSNAT, 1986). Also a model was used within this program to predict daily soil water conditions for field operation delays.

Chen (1987) developed a microcomputer model for selection of machines and tractors. Equipment was pre-selected to be capable of completing tasks on time. Then, a tractor was sized to provide the right amount of power to operate the equipment. In this model, the user must identify the primary operation requiring the highest draft. In most farms with one principal tractor, this operation would be primary tillage.

The user inputs acreage, available field working hours, operating speed and field efficiency of the primary operation. Then, the model calculates the required capacity and corresponding equipment width. The user selects a piece of equipment from the given equipment file so the chosen equipment has a size equal to or larger than the required equipment width. If no suitable implement is available, the user must select the largest one in the equipment list. The user has the option to input and thus modify the equipment file.

Once the equipment width for the primary operation is chosen, the next step is to choose the tractor. The user inputs the draft for the operation and soil condition. The model then calculates the required tractor horsepower. The equipment for all other operations using the common tractor is selected next. For farms with multiple tractors, each of the secondary tractors is selected using the same procedure used to select the principal tractor.

Whiston et al. (1981) developed a machinery selection model considering weather risk. This model selects a machinery set that has enough capacity to finish all critical field operations on time. By considering different weather risk levels, the machinery size associated to a risk level differs from the machinery size for other risk levels. The model provides an opportunity to examine weather effects on the selection of machinery complements.

2.2 Least-Cost Models

The second approach can be called “Least - Cost Models” in which the least-cost combination of machinery is determined for a specific farm situation. In this case, an economic penalty is estimated for late operations. This penalty, which farmers pay indirectly when critical field operations such as planting and harvesting are not completed within an optimum period, is assumed to result from a reduction in quantity and/or in quality of harvested crop. This approach can also be called an optimization method which is capable of modeling a complex agricultural problem. It allows the farm manager to look

at the effect of changing parameters as well as model sensitivity and limits of these changes. It also allows the farm manager to recognize the full potential of the agricultural system. The main objective of this type of model is to select optimum machinery complements and also optimize working schedules. However, sub-objectives of these models differ greatly.

Ozkan and Edwards (1986) developed a microcomputer-based computer model called "Farmer-Oriented Machinery Comparison Model." It was developed to investigate the effect of changing machinery and crop production parameters on machinery costs, timeliness costs, and the income generated from production of crops on a corn/soybean farm. Machinery ownership, operating costs, and labor costs of each user-specified field operation are estimated. Completion periods of the field operations are predicted based on the sizes of machines, labor available, expected suitable field days, and the acreage farmed. Timeliness costs are estimated based on the predicted planting and harvesting dates. Five examples were chosen to illustrate the usefulness of the model. The parameters varied were hours of labor available each day for field operations, the tillage equipment size, and the number of tillage operations performed on a 234-ha (600 acres) corn/soybean farm. Each of these comparisons demonstrated how net income is affected by simultaneous changes in machinery ownership costs, machinery operating costs, and crop yields through improved timeliness.

Production parameters, such as earliest beginning dates of field operations, geographical location of the farm, total acreage planted, proportion of acreage planted to

each crop, and expected yield reductions by missed planting and harvesting dates, could also be modified by the user to determine their effects on farm income. Economic parameters that could be varied include interest rate and crop prices. By supplying and varying these parameters, the user has the flexibility to describe many individual machinery/crop situations and search for profitable trade-offs among ownership, operating and timeliness costs.

Colvin et al. (1986) developed a simulation model to select optimum machinery sets for a hypothetical 250 hectare southeastern Iowa grain farm. It reported optimum machinery sets for three tillage systems: conventional, reduced, and slot-plant. The objective of this model was to demonstrate the dramatic effects on machine requirements when tillage is reduced on a fixed acreage. It has implicitly taken timeliness into account by restricting the probability for field work to the 90% level (or 9 years out of 10). The probability level was the same for each system to keep the timeliness of operations constant across all tillage systems. The values chosen for efficiency and speed for calculating machine capacity came from a large-plot research project in southeastern Iowa. It allows the model user to use specific field-verified data for each of the three tillage systems. This increased the accuracy of determining optimum machinery sizes.

Ozkan et al. (1991) developed a simulation model called DREMS to evaluate drainage effects on machinery selection. DREMS combined a machinery cost model, a yield loss estimation model called TIMECOST, and a drainage cost estimation model called DRAINMOD. One of the unique aspects of this model was its ability to determine

soil trafficability conditions for a given day and soil type. Therefore, in contrast to limited use of current timeliness cost calculation procedures, TIMECOST can be used to determine the timeliness cost associated with corn planting in a poorly drained soil in any of the corn belt states. The model, however, requires accurate data on weather, soil, crop production and drainage parameters. Due to the limitations of the DRAINMOD yield version, the TIMECOST model cannot determine the timeliness costs associated with harvesting. Also, it cannot be used to evaluate timeliness costs associated with crops other than corn. In spite of these shortcomings, the TIMECOST model provided a new timeliness cost calculation procedure that is applicable to a wide range of locations. Using this model, one can perform sensitivity analyses by changing drainage capacity and machinery systems and seeing their effects on the timeliness cost. The most economical combination of machinery and drainage system for a given farm could then be found.

2.3 Whole Farm Machinery Management System

The third approach can be called “ Whole Farm Machinery Management System.” Like the “Problem Solving Model.” this approach does not derive optimum machinery size and/or number for the given farm. It utilizes weather data, machinery capacities, labor availability, and information on operators, tractors, and implements for evaluating the operational behavior of a farm system. It integrates conventional programming with expert system techniques of artificial intelligence for analyzing simulation results and presenting recommendations to the farm manager. Expert system technology allows someone who is

not an expert in a particular field to make decisions based on the knowledge and experience of experts in that field. This type of model can serve as a decision support system.

Oskoui et al. (1990) developed a model of this kind called a knowledge-based machinery management system. This model has two distinct modules: A process oriented simulation module and knowledge based, objective selection module.

The first component of this management system simulates a given farming system with a given climate, soil type and cropping conditions and calculates a series of alternatives and feasible machinery systems. It also creates a series of rules by which the most suitable machinery system can be chosen.

The second component of the system combines rules created by the first module with the knowledge acquired from domain experts to interrogate the user and select the most suitable machinery systems from a pool of possible systems created by the first component of the system. The user is asked some questions according to the results generated by the first component of the system. The user chooses suitable answers to each question and makes intermediate decisions that can eliminate the most unlikely choices throughout the interrogation process. Finally the expert system will recommend an optimum machinery set. The user's interrogation of the system alters only the conclusions drawn from a certain question rather than altering the internal knowledge of the system. The candidates are selected by either automatic elimination by the program depending on

the conclusions of the answers or manually by narrowing down the choice listed in the manual selection mode.

By combining knowledge system techniques with conventional problem solving techniques, Freeman and Whittaker (1992) developed an object-oriented simulation model. It establishes a calendar of operations based on the existing farm resources and uses an algorithm to check the feasibility of the defined calendar. This algorithm, used to check the physical feasibility of the calendar, does not involve formal optimization procedures. It does, however, perform a daily search procedure to ensure that the operations can be completed by the defined ending dates without violating any resource constraints (time, labor, and machinery) defined by the farmer. The calendar is used to determine if all of the work is completed during a normal operating year, with normal operating procedures. If the work cannot be completed under normal conditions, then changes in operating procedures are suggested by the expert system.

One of the unique aspects of this expert system is its ability to help the farmer address within-season problems that may arise during production. These within-season problems might include the loss of labor due to injury, the loss of equipment due to machinery breakdown, and or the loss of time due to adverse weather conditions. For example, if field operations are delayed due to weather or machinery breakdown, the expert system helps the farmer assess the consequences of the delay. The expert system proceeds from the day the field operation is expected to be continued and checks that the operation can still be completed by the desired ending dates. If the operation cannot be

completed, the expert system calculates the required increase in operating rate needed to finish the operation by the ending date and the extra time required to complete the operation at the normal rate. Based on the increase in operating rate and the extra time required for completion, the expert system makes suggestions for correcting the problems.

The other unique aspect of this expert system is its ability to help the farmer with long-term problems. These long-term problems may include renting or purchasing additional land, the loss of labor source, or a change in the machinery complement (tractor(s) and/or equipment). For example, if the farmer is considering additional acreage, the farmer would need to know the difference between an increase in acreage that could still be farmed with the farm's current machinery and labor resources and one that would require a change in these resources. This is important because of the high initial cost of investing in new or larger equipment. The farmer can use this expert system to increase the acreage of particular crops to recognize which crop will allow the largest increase in acreage before additional machinery is required.

Lal et al. (1992) developed a whole-farm machinery management decision support system. The overall goal of this system was to provide a planting and or management tool for researchers, educators, and farmers to test different combinations of resources such as equipment, crop mixes, and labor for different crop-management strategies over a variety of weather years. It can evaluate the timeliness of different operations, the utilization efficiency of farm resources (labor and machinery), and their effects on crop yields. This decision support system also guides the user in revising cropping patterns, and in

improving the utilization of machinery and labor. It can help evaluate the performance of different farms for a particular weather year or performance of the same farm over different weather years. The system consists of four components: Information Manager, Operation Simulator, Expert Results Analyzer, and Yield Estimation System.

The Information Manager works as an intelligent front end for the entire system and collects farm information. The Operation Simulator simulates field operations with a one-day time step for all fields on the farm for the complete growing season. It produces three types of reports, namely, work, no-work, and summary reports. The work report contains information about the work performed during a simulation. The no-work report contains information about tasks attempted that could not be done because of factors such as non-availability of machinery or excessive rain during the day. The summary report compiles information in work and no-work reports specific to each operation. The Expert Results Analyzer helps the user decide on actions appropriate for improving their farming operations. It evaluates the Operation Simulator reports (work, no-work, and summary) in the context of the resources available on the farm. It analyzes timeliness of different operations for their delayed start and/or completion. It studies the utilization efficiency of machinery and labor and identifies their excesses or deficits on the farm. Yield Estimation System is used to predict production for the farm or for different fields or crops, individually. It can help assess the impact of field level management decisions (such as crop variety selection, irrigation, fertilization), farm level planting strategies (machinery numbers, and their capacities, seasonal work schedule, etc.), and regional

characteristics (sale prices, and production costs of different crops) on overall farm production, gross revenue and net profits from different fields and crops.

2.4 Model Selection

Most of the models developed to deal with machinery selection employed the second approach -- optimization method. Optimum machinery selection has no agreed upon universal criteria for choosing the “best” machinery set (Edwards and Boehlje, 1980), and the process of optimization is a bottleneck in any farm management study because of the complex nature of the machinery system and machinery diversity with respect to type, size, number, operational characteristics, and of the stochastic nature of weather. The process is further complicated in multiple field cropping because the optimal selection must satisfy the operational requirements of all crops simultaneously with constraints of maximum efficiency and minimum capital investment (Haffar and Khoury, 1992). Some recently developed computer simulation models are more likely to consider more factors and employ more complicated procedures and criteria. This makes model development more expensive and difficult to use and understand. However, such complicated models are not necessarily more accurate than those developed in a basic and reliable way such as the Farm Machinery Selection Program, version S10, developed by Siemens et al. (1992).

The Farm Machinery Selection Program has some advantages over other computer simulation models dealing with machinery selection and operations scheduling:

a). This program has been run on over 50 actual farm situations so far. In essentially all cases, comments concerning the program have been positive, and the results presented have been satisfactory.

b). The program was developed so the user can gain an understanding of many farm machinery management principles.

c). The required data inputs are simple compared to other programs. The program provides a default value for each input obtained from the author's many years of experience under the Midwest weather and soil conditions. The user can easily modify data used by the program.

d). The methodology employed by the program was simple and proven to be reliable. It divides the total machinery related costs into three categories: machinery ownership costs, machinery operating costs, and timeliness costs, and uses the least-cost approach to search for the optimum machinery set with lowest costs for a specific farming enterprise.

e). The program outputs not only one but eight lowest cost machinery sets found during the optimization procedure. The output information associated with each of the eight machinery sets includes optimal field operation schedule, annual machinery use, annual machinery ownership and operating costs, and timeliness costs for each field operation. The results are easy to understand.

Chapter 3

Program Overview

The main objective of this study was to adapt the Farm Machinery Selection Program originally developed for Illinois to Virginia agriculture. The program was written in C and runs on an IBM compatible personal computer. The objective of this program is to assist farm managers in selecting the least cost set of farm machinery for their farms.

The program input information consists of a list of desired field operations with start dates, acres, and hours per day for each operation. Other input includes crop yield, penalty dates for planting and harvesting, availability and cost of labor, and certain economic data such as crop prices and current interest rate. These inputs are farm-oriented data provided by the program user. Stored data files contain machinery list prices and productivity values, work-day probabilities, and equation constants for computing machine costs. For different machinery sets or a specified set of machinery, the program schedules the field operations and computes the total machinery-related costs including costs for machines, labor, and timeliness. The program uses an optimization process to find the lowest-cost machinery set and determine the eight lowest cost sets. For any of the eight lowest cost sets, or for a specified set of machinery, the program outputs a list of machinery with prices and annual use, the work schedule, the cost for each operation, and total machinery-related costs.

3.1 Required Input Data

The required input data sets are those that must be provided by the user. Data sets are assumed to be different between farms and some of them, such as economic factors might change periodically.

3.1.1 Crop Prices, Yields and Penalty Dates

Before the program can be used, some assumptions on crop prices, expected yields from crops if there is no penalty, and penalty dates for each crop must be made.

These inputs (Table 3.1) are used to calculate timeliness costs when field operations are scheduled with a set of machinery. When a crop is planted on and before the entered planting penalty date and is harvested on and before the entered harvesting

Table 3.1 Crop Prices, Yields and Penalty Dates (Default Values for Illinois)

Crop	Prices (\$/bu)	Yield (Bu/A)	Penalty Dates	
			Planting	Harvesting
Corn	2.50	150.0	5/15	11/15
Soybeans	7.50	40.0	5/31	10/15
Wheat	3.00	60.0	10/30	7/20
Oats	7.50	40.0	5/31	10/15
Sorghum	7.50	30.0	6/6	11/1

penalty date, the yield is assumed to be equal to the yield entered for the crop. When a planting or harvesting operation occurs after the penalty date, a yield decrease is assumed and a timeliness penalty is calculated.

3.1.2 Timeliness Factors

Timeliness factors include factors for later planting and factors for later harvesting for each crop. These factors indicate the percentage of yield losses per day of delay (Table 3.2).

Table 3.2 Timeliness Factors (Default Values for Illinois)

Crop	Timeliness Factor	
	Planting	Harvesting
	% yield loss per day of delay	
Corn	1.0	0.5
Soybeans	1.0	1.0
Wheat	0.25	1.0
Oats	1.0	1.0
Sorghum	0.25	1.0

For example, the default timeliness factor of later planting for corn in Illinois is 1.0 (Table 3.2). This means that if corn is planted one day later than its planting penalty date entered as in Table 3.1, then 1% yield reduction is assumed. If corn is planted two days later than its penalty date, then $2 \times 1\% = 2\%$ yield reduction is assumed.

3.1.3 Economic Factors

Economic factors include 1) purchase price, 2) housing, interest, and insurance rates, 3) percent inflation, 4) fuel price (\$/Gal) (Table 3.3). These factors are required for calculations of machinery fixed and variable costs. Costs for housing, interest, and insurance are estimated by multiplying the percentage entered for these factors by the

remaining farm value (rfv) of the machine. Housing costs typically average from 1 to 2% of the rfv, interest rates vary but usually will be in the range of 8 to 12% of the rfv, and insurance is assumed to be 0.25 to 0.5% of the rfv (Bowers, 1987).

3.1.4 Labor Availability and Cost

The program user must specify the amount of labor available on the farm and the cost of labor. Wages may be entered on an annual or hourly basis. As field operations are scheduled, annual working hours for each operator are calculated by the program, and total labor costs are calculated. The maximum number of laborers the program can handle is six (Table 3.3).

3.1.5 Field Operations Desired for the Farm

The most critical input information is the list of desired field operations to be performed and date related to each operation (Siemens et al., 1988). The program user must enter the total tillage acres for the farm (Table 3.4).

Table 3.3 Entry Screen for Economic and Timeliness Inputs

Enter ECONOMIC and TIMELINESS Data	
Operators:	
Number: 2	Cost (\$/hr): 7.5
Economic Factors:	
Purchase Price, % of List:	90.0
Housing, Interest, and Insurance:	12.0%
Percent Inflation:	3.5%
Fuel Price (\$/Gal):	\$1.00

Table 3.4 Operation Entry Screen for an Example Farm

Enter Data For FIELD OPERATIONS						
Tillable Acres:		1000.00				
Code No.	Field Operations	Earliest Start Date (Mo / Day)	Latest Finish date (Mo / Day)	Acres	Labor Availability (Hrs /Day)	Land Area
2	Combine Soybeans	9 15	0 0	500.0	10.0	1
1	Combine Corn	10 15	0 0	500.0	10.0	0
7	Chisel Plow	10 15	0 0	500.0	10.0	0
8	Disk Harrow	4 1	0 0	500.0	10.0	1
9	Field Cultivate	4 25	0 0	500.0	10.0	1
21	Plant Corn	4 25	0 0	500.0	10.0	1
8	Disk Harrow	4 1	0 0	500.0	10.0	0
9	Field Cultivate	5 1	0 0	500.0	10.0	0
22	Plant Soybeans	5 1	0 0	500.0	10.0	0
18	Row Cultivate	6 1	0 0	500.0	10.0	1
18	Row cultivate	6 10	0 0	500.0	10.0	0
0	no operation	0 0	0 0	0.0	0.0	0

The first column is the code number of operations. There are thirty operations available within this program. In order to make the entry easy for the user, the program assigns a code number for each operation as its reference number. By doing so the user does not need to enter the entire operation name but its code number. The program adds the operation name automatically behind the code number in the second column. For example, if 2 is entered in the first column, the program will add COMBINE SOYBEANS behind the number 2 in the second column.

The third column is the Earliest Start Date for the operation and must be provided by the user. For example, the earliest start date for combining corn in Table 3.4 is October 15. This is interpreted to mean that October 15 is the earliest date corn is commonly ready for harvest in the region of the example farm.

The fourth column is the Latest Finish Date for the operation. It is an optional input. The latest finish date can only be used to prevent the program from trying machinery sets that are not acceptable. In other words, if a latest finish date is specified for an operation, the program will select only machinery sets that have capacities to finish this operation on or before this latest finish date. If the user leaves the latest finish date column of an operation blank (0 / 0) the program will try all the possible machinery sets and determines a finish date for this operation. For planting and harvesting operations, if the calculated finish dates are later than the penalty dates entered, the program will calculate the timeliness costs.

The fifth column shows the acres covered for the operations, and the sixth column shows hours per day for the operation. This column indicates the hours per day the operation can be performed assuming the day is a good working day, or the number of hours labor is available per day. The program assumes that the number of hours per day are the hours spent in the field operating machinery, and no allowance is made for time required to prepare for going to the field or for traveling to the field.

The last column is the land area number. Land area numbers are used to help insure that the operations are scheduled correctly. To determine the land area number for

each operation, the farm is divided into areas on which the same set of operations are to be performed and each area is given a different land area number (Siemens et al, 1988). For the example farm presented, there are two land areas for the corn-soybean crop rotation. A land area number of “0” was entered for all operations to be performed on the land from which soybeans are to be harvested. Likewise, a land area number of “1” was entered for all operations to be performed on the land from which corn is to be harvested. Allowable land number areas are 0 through 4. This means that the program can handle 5 different areas for a specific farm (Siemens et al., 1988).

3.1.6 Machinery Data

The user provides machinery data including tractor, combine, and implement data (Table 3.5). There are nine tractor sizes and four combine sizes available within the program. This means that the program can only select tractor sizes and combine sizes from these available power units.

The program provides three run options: 1) with optimizing, 2) without optimizing, 3) with complete optimization. If the program runs “with optimizing,” the number of tractors and the number that are large and small must be specified (Table 3.6). The number of combines must be specified also. The program optimizes the sizes of the tractors and combines specified by the user. If the program runs “with complete optimization,” the program optimizes number and size of tractors and size of combines. The program user does not need to specify the number of tractors, but still needs to

Table 3.5 Entry Screen For Tractor and Combine Data

Enter Data for TRACTORS and COMBINES					
	Quantity	Size*		Quantity	Size*
Tractors:			Combines:	1 (Max = 3)	2
Large	1	5	Corn Heads:	1 (Max = 3)	
Small	1	1	Grain Platforms:	1 (Max = 3)	
Total (Max = 6)					
* Needed To Run Without Optimization.					
Available Tractor Sizes:			Available Combine Sizes:		
0 = 60 HP	5 = 160 HP		0 = 140 HP	(4 Row Head)	
1 = 80 HP	6 = 180 HP		1 = 180 HP	(6 Row Head)	
2 = 100 HP	7 = 200 HP		2 = 215 HP	(8 Row Head)	
3 = 120 HP	8 = 240 HP		3 = 260 HP	(12 Row Head)	
4 = 140 HP					

specify the number of combines, and the number of corn heads and grain platforms. If the program runs “without optimization,” the user needs to enter the number of tractors and their sizes, the number of combines and their sizes (Table 3.5). The program does not optimize anything with this option. This option can be used to check the feasibility and capacity of a specified machinery set for a farm.

On the implement data entry screen (Table 3.6), the number of large and small tractors previously set on the Tractor Data screen is shown in the upper right. The program user specifies the planter size. If the user chooses “T”, then the planter used in the program will be twice the combine size (number of rows on corn head).

Table 3.6 Entry Screen for Implements

Match IMPLEMENTS to TRACTORS					
Planter Size : S (T or S)			Large Tractors: (L):		1
(T): Twice the combine size			Small Tractors: (S):		1
(S): Same as Combine Size			Total:		2
Implement	L	S	Implement	L	S
Moldboard Plow	0	0	Spray Pesticide	0	0
Chisel Plow	1	0	Drill	0	0
Disk	1	0	Subsoiler	0	0
Field Cultivate	1	0	Paraplow	0	0
Chop Stalks	0	0	Chop Forage	0	0
Plant	0	1	Combination Tool	0	0
Row Cultivate	0	1	Mow Hay	0	0
Rotary Hoe	0	0	Rake Hay	0	0
Apply Anhydrous	0	0	Mow & Condition	0	0
Apply Fertilizer	0	0	Bale Hay	0	0

The user must also specify the number of implements and assign the implements to either the large or small tractors. The user must determine which operations are to be performed by the large tractors and which are to be performed by the small tractors. The user may assign implements to both large and small tractors. It may be necessary to try different implement assignments and by trial and error find the particular assignments which results in the lowest total cost. The number “ 1” in Table 3.6 under column L (or S) means this implement is assigned to a Large (or a Small) tractor. Chisel plow, for example, is assigned to a large tractor in Table 3.6.

3.2 Stored Data Files

Stored data files limit the amount of data required from the program user and can be changed by the user. The stored data files include tractor and tillage implement file, combine file, planter and cultivator file, file for calculating machinery fixed and variable costs, and work-day probability files. These stored files are described below.

3.2.1 Tractor and Tillage Implement File

This file contains a list of matched tractors and implements available within the program. The tractor sizes vary in increments of 20 horsepower from 60 to 240 horsepower. A set of tillage implements are pre-matched to each tractor. For each tractor and implement, the file contains the machine size and name, estimated productivity for the tractor/implement combination, and a list price (Appendix A, Table A1). A list price of 0.00 for fertilizer application and sprayers assumes these implements are made available to the farmer at no charge. If a tractor does not have sufficient power to pull an implement the productivity is set to 0.0 in the file. For example , for an 60 horsepower tractor the productivity for chisel plowing is 0.0. The program will not allow the 60 horsepower tractor to be used for chisel plowing. The essential methodology used to match implement sizes to tractor power and to calculate productivity is given in ASAE Standards (1987) and is discussed in chapter four.

3.2.2 Combine File

The combine file contains the size, name, and list price of four combines of sizes 140, 180, 215, and 260 horsepower (Appendix A, Table A2). For each combine, the file contains a matched corn head and grain platform with productivity values and list prices.

3.2.3 Planter and Row Cultivator File

There are two parts to this file. The first part includes matched pairs of planters and cultivators along with estimated productivity and the list price of each (Appendix A, Table A3). The second part of the file is an array used to match the tractors, combine corn heads, and planters. The array provides a choice of the same number of rows on the planter as on the corn head. A constraint imposed is that the tractor, planter and row cultivator sizes must be compatible in regard to available or required power.

3.2.4 Machinery Fixed and Variable Costs File

The machinery fixed and variable costs are calculated for each machine after the operations are scheduled. The following machinery costs are estimated in the program:

Fixed costs: depreciation, interest on investment, housing, and insurance.

Variable costs: repair and maintenance, lubricants, and fuel.

The machinery purchase price is equal to the list price multiplied by the “purchase price, % of the list” entered. The percent of life is used to determine the number of years costs are calculated for a machine:

1. If the machine use reaches 70 percent of its life and the machine is less than five years old, the machine is assumed to be sold and a new machine is purchased.
2. If machine use reaches 50 percent of its life and the machine is five years old or more, the machine is assumed to be sold and a new machine is purchased

The assumed life of each machine is given in Appendix A, Table A4.

The file contains constants for the equations used to estimate the fixed and variable machinery costs. The constants and the formulas were obtained from Wendell Bowers, a professor of agricultural engineering at Oklahoma State University (Siemens et al., 1988). Bowers presented the formulas in his textbook (Bowers et al., 1986) and similar formulas appear in ASAE Standards (1992). The formulas are discussed further in chapter four.

3.2.5 Work-Day Probability file

Probabilities of a day being suitable for field work are included for northern, central, and southern Illinois (Appendix A, Table A5). The program user must select which region to use. Probabilities are from Schwart (1981) and represent the fraction of time during the year that field work is feasible at least 5 of 6 years (83.3% of time).

3.3 Run Options

The program provides three run options. They are 1) run with optimizing, 2) run with complete optimization, and 3) run without optimizing.

1) Run With Optimizing: this option may be used to optimize the sizes of the tractors and to determine the work schedule, machinery use, and costs with optimized sizes of tractors. This mode only optimizes the sizes of the tractors. The number of the tractors and the number that are large and small must be specified by the program user. In order to optimize the number of tractors with this option, the user may run the program with a different number of tractors and compare the results. This mode also optimizes the sizes of combines but does not optimize the number of combines. To optimize the number of combines, it is necessary to run the program with different numbers of combines and compare the results (Siemens et al., 1988).

2) Complete Optimization: this option may be used to optimize both the number and sizes of the tractors. The user does not need to enter tractor data, but still needs to specify the number of combines. Even with this option, this program does not optimize the number of combines. When the program user chooses this option, he or she should be aware that this option has not been checked fully (Siemens et al., 1992) and only can handle two tractors and four operators.

3) Run without optimization: This option may be used to determine the work schedule, machinery use, and costs with the number and sizes of the tractors specified by

the program user (Siemens et al., 1988). When the program user selects this run option, the program does not optimize the number and sizes of tractors for the user. The user must specify the number of tractors, the sizes of tractors, how many are large, and how many are small. The program does not optimize the number and sizes of combines and the user must specify the number and sizes of combines. This option is always used to check the feasibility of the specified machinery set and calculate machinery related costs.

Chapter 4

Methodology Used in The Program

This chapter describes the methodology used by this program. It involves many concepts of machinery management, such as considering weather risk consideration in machinery selection, matching equipment to tractors and combines, estimating machinery productivity, calculating machinery fixed and variable costs, and optimizing machinery costs.

4.1 Weather Uncertainty and Timeliness

Variations in weather during critical field operations result in uncertainty regarding the amount of machinery that must be purchased. For example, a manager could reduce risk due to weather if the crop could be planted in half the time normally required for planting. Thus, in years of heavy rainfall the farm manager may still get the crop planted within the desired (optimal) planting period. However, additional machinery required would cause average machinery costs per acre to be higher than the machinery costs the manager planned for average or normal planting weather. Conversely, if the machinery set purchased has just enough capacity to allow planting crops in the time normally required for planting, the farmer may not get the crops planted on time in the years of heavy rainfall. In a case like this, timeliness costs (penalty for not completing the task) would be expected and could be very high. Between the extremes, there is an optimum level of

machinery which balances the timeliness costs and machinery ownership and operating costs.

4.1.1 Available Field Working Days

Estimating the timeliness costs requires determination of the number of available field working days. Available field working time is defined as the working days in a scheduled period in which field operations can be performed (Wetzstein et al., 1990).

One approach used to determine the number of field working days is based on simulated soil moisture conditions. Whether a day is suitable for field work depends largely on the soil trafficability which is related to the soil type and soil moisture condition. A model based upon climate and soil data has been used to predict the available field working days in Michigan considering soil moisture and soil properties (Rosenberg et al., 1982). Soil moisture and trafficability were determined for six categories of field operations. The model was tested by comparing simulated working days to actual working days.

A different approach used to determine the number of field working days is based on observational data. The number of available field working days was estimated weekly or multi-weekly at a probability level throughout a year. This is the approach employed by this program. The reason this method was chosen is because it is relatively easy to implement.

Weather conditions may vary from region to region. Within this program, Illinois was divided into three regions: Central, Southern, and Northern Illinois. Calendar days favorable for field work were collected for selected dates of 1984 to 1989 (Table 4.1).

Table 4.1 Calendar Days Favorable for Field Work by Selected Period and Regions of Illinois

Total Calendar Days	Average Number of Favorable Days			Number of Favorable Days Available 5 out of 6 years		
	Days	Northern	Central	Southern	Northern	Central
March 27- April 0914	4.1	5.9	3.0	1.7	2.0	1.0
April 10 - April 2314	7.9	6.9	6.4	5.0	3.6	2.4
April 24 - May 714	9.2	7.9	7.8	6.2	5.1	4.2
May 8 - May 2214	8.6	7.5	8.0	5.4	3.9	4.2
May 23 - June 414	10.2	9.1	9.4	8.2	6.5	6.0
June 05 - June 1814	9.7	9.5	6.5	6.4	6.4	7.0
June 19 - July 2 14	10.8	10.0	10.8	8.6	7.1	8.0
Aug. 30 - Sept. 1214	11.9	11.3	12.1	9.3	9.8	9.5
Sept. 13 - Sept 2614	10.2	9.6	10.8	6.6	7.2	8.2
Sept 27 - Oct. 1014	10.7	9.4	10.3	6.7	7.9	7.6
Oct. 11 - Oct. 2414	11.5	10.8	10.6	8.8	10.0	8.1
Oct. 25 - Nov. 714	10.4	10.5	10.6	6.4	7.2	7.6
Nov. 8 - Nov. 2114	10.3	10.0	8.6	7.9	8.1	7.6
Nov. 22 - Dec. 614	6.5	7.5	4.8	5.9	3.7	1.6

In this table, two kinds of observed data include Average Number of Favorable Days and Number of Favorable Days Available 5 out of 6 years. The Average Number of Favorable Days is the mean of the observed data over several years, while the Number of Favorable Days Available 5 out of 6 years means that the number of favorable work days could be expected five out of six years. Example data are shown for the period April 5-11 from 1987 to 1992 (Table 4.2).

The Average Number of Favorable Work Days can be calculated as:

$$(2.8 + 3.9 + 3.3 + 4.1 + 4.0 + 5.5)/6 = 3.93 \text{ (days)}$$

Table 4.2 Number of Days Suitable for Fieldwork, Selected Dates 1987-1992

Period	1987	1988	1989	1990	1991	1992
•	•	•	•	•	•	•
•	•	•	•	•	•	•
•	•	•	•	•	•	•
April 5 - 11	2.8	3.9	3.3	4.1	4.0	5.5
•	•	•	•	•	•	•
•	•	•	•	•	•	•
•	•	•	•	•	•	•

Number of favorable days available 5 out of 6 years can be obtained by selecting the fifth largest number from these six numbers, in this case, 3.3 days. This means 3.3 favorable work days could be expected during the period from April 5 to April 11 five times in the next six-year period .

The program uses the second group of data (number of favorable days available 5 out of 6 years) to calculate suitable fieldwork days, because this group of data is more conservative than the first group. The time periods shown in the table by Schwart (1990) (observation data used by this program) is two weeks, while the prob1-5.tjk files (work-day probability files) use a time period of one day. The probability data in prob1.jtk - prob5.jtk files are derived by dividing corresponding figures in Schwart's table by 14. For example, in Schwart' s table, number of favorable days available 5 out of 6 years in southern Illinois during April 10 to April 23 is 2.4 days (Appendix A, Table A5). Then in

prob2.jtk (Appendix A, Table A6) during April 10 to April 23, only 17% ($2.4/14=0.17$) of each day could be expected as a good field work day.

4.1.2 Timeliness Costs

Timeliness is defined as the ability to perform an activity at such a time that crop return is optimized, considering quantity and quality of production (ASAE Standard, 1992). The economic benefit of timeliness is evaluated by the timeliness cost which varies by region, crop variety, time of the season, and machine operations. Estimating the timeliness penalty has been one of the most difficult and weakest aspects of machinery selection models. Several general timeliness factors have been published (ASAE Standard, 1987). These factors, however, have been obtained from different locations in only a few states and do not provide accurate timeliness cost values when used for other locations. For this reason, only a few machinery selection studies have considered timeliness cost.

Timeliness penalty is usually assumed when a crop is planted before or after an assumed optimal planting period for the crop, or the crop is harvested before or after an assumed optimal harvesting period. To estimate timeliness costs, the program user provides optimal dates of planting and harvesting for a crop. Chancellor and Cervinka (1979) assumed a function that has linearly decreasing and increasing functions before and after an optimum period (Fig. 4.1). Edwards and Boehlje (1980) used a continuous quadratic function derived from experimental data in several regions of Iowa to estimate the percent yield reduction as a function of planting or harvesting date (Fig. 4.2).

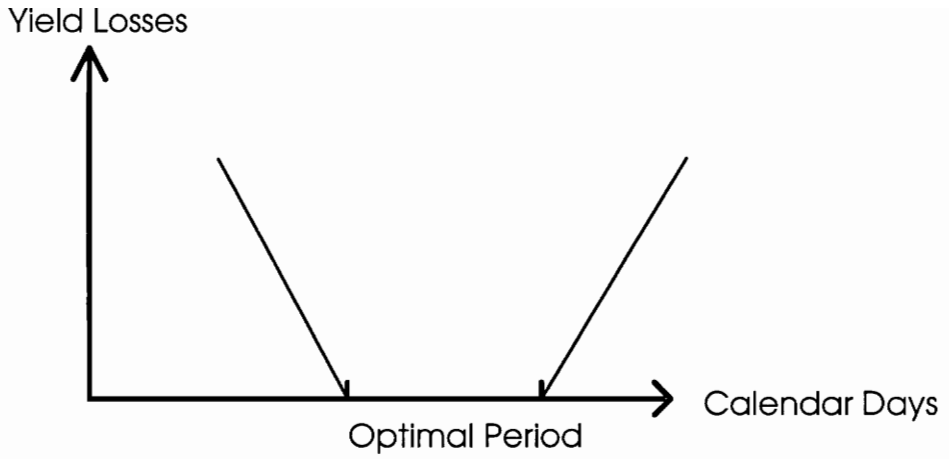


Figure 4.1 Chancellor's Function for Estimating Yield Losses

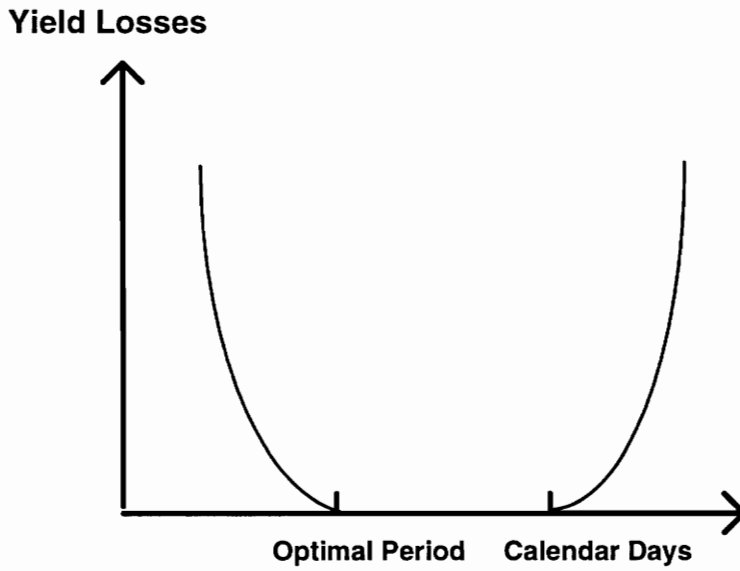


Figure 4.2 Edwards's Quadratic Function for Estimating Yield Losses

Within this program, the program user needs to specify the optimum planting and harvesting dates for each crop. But only later planting and harvesting are considered to be causes of yield reduction, however, because this program does not schedule planting or harvesting operations before the optimum planting and harvesting dates. The program author used a rule of thumb of yield reduction for each crop. If corn, for example, is planted one day later than the latest optimal date, this program will assume 1% yield reduction. The percentages of late planting and harvesting for each crop can be specified by the program user.

4.2 Matching Equipment Sizes to Power Units

A major task facing the modern farmer is to match power units to the size and type of machinery so all field operations can be carried out on time with minimal cost. When the amount of power of the power unit limits the size of equipment that can be used with it, it is important to match the units correctly. If a tractor is oversized for an implement, costs will be excessive for the work done. If the implements selected are too large for the tractor, the quality or quantity of the work may be lessened or the tractor will be overloaded, usually causing expensive breakdowns.

4.2.1 Matching Implement Sizes to Power Units

The essential methodology used within this program to match the size of implements to tractor power and calculate productivity is given in ASAE Standard (1987). For a specific field operation and soil type, ASAE Standard gives a formula to calculate the draft per unit. For example, the soil type in northern Illinois is silty clay, then the formula for calculating draft data for the field operation of moldboard plowing according to the ASAE Standard is given as below:

$$Draft = 7 + 0.09 S^2 \text{ (lb / in.}^2\text{)}$$

For the sandy silt soil type, the formula for calculating the draft data for a moldboard plow is given below:

$$Draft = 3 + 0.056 S^2 \text{ (lb / in.}^2\text{)}$$

where S is the field speed in mph.

This speed (mph) for field operations is also recommended by the ASAE Standard (1992). The speed range for a moldboard plowing is from 3.0 to 6.0 mph. The recommended typical speed for this field operation is 4.5 mph. So the draft of moldboard plow for silty clay soil type in Northern Illinois can be calculated as:

$$\begin{aligned} Draft &= 7 + 0.09 \times 4.5^2 \\ &= 8.825 \text{ lb / in}^2 \end{aligned}$$

After the draft data and recommended field speed are obtained, the size of implements can be matched to tractor power using the following formula:

$$HP = \frac{D (\text{lb} / \text{in}^2) \times W (\text{in}) \times d (\text{in}) \times S (\text{mph})}{375}$$

Where D = specific draft or draft per unit

W = width of tilled zone

d = depth of tillage

S = forward speed

For a 4*16 moldboard plow, the width of the operation is 16 inches. If the depth of the tillage is 10 inches, then the required power unit for this implement would be:

$$\begin{aligned} HP &= \frac{D (\text{lb} / \text{in}^2) \times W (\text{in}) \times d (\text{in}) \times S (\text{mph})}{375} \\ &= \frac{8.825 \times 64 \times 10 \times 4.5}{375} = 67.776 \text{ horsepower} \end{aligned}$$

For a 4*16 moldboard plow, the required tractor size is greater than 65 horsepower. Within this program, there are 30 field operations. This means 30 different kinds of implements of many available sizes can be matched to tractors or combines.

4.2.2 Estimating Productivity Values

The productivity of a machine combination (tractor/implement or combine/attachment) is the rate of performance. It is important to select power units and equipment so that important field operations can be completed on time. It is also important, however, to avoid the added expenses of larger-than-necessary machines. Three methods of measuring capacity are field capacity, material capacity, and

throughput capacity. Field capacity, usually expressed in acres per hour, is the most commonly used measure of machine capacity.

Field capacity is determined by three factors:

1) Speed - Speed is the average rate of travel expressed in miles per hour (mph).

Different field operations have different recommended speeds. As discussed in the last section, recommended field speed for each field operation is provided in the ASAE Standard (1992). Typical speed for moldboard plowing, for example, is 4.5 miles per hour.

2) Width - Width is the distance in inches across the processing portion of the machine. For an 4*16 moldboard plow, the width of the operation is $16 \times 4 = 64$ inches.

3) Efficiency - Efficiency is the ratio of the effective capacity of a machine to its theoretical capacity. It is an indicator of how much time is spent working versus turning, filling hoppers, and other jobs. Range of efficiency for each field operation is also provided in the ASAE Standard (1992). The field efficiency for a moldboard plow, for example, is considered to be 70% to 90%.

The effective field capacity can be estimated using the following formula:

$$\text{Effective Field Capacity} = \text{Efficiency} \times \frac{\text{Speed (mph)} \times \text{Width (ft)}}{8.25}$$

If a tractor with a 4*16 moldboard plow travels at a speed of 4.5 miles per hour, and the field efficiency for this operation is 80%, then, the effective field capacity for this combination is:

$$\begin{aligned} \text{Effective Field Capacity} &= \text{Efficiency} \times \frac{\text{Speed (mph)} \times \text{Width (ft)}}{8.25} \\ &= \frac{80}{100} \times \frac{4.5 \times 5.33}{8.25} = 2.33 \text{ acres / hour} \end{aligned}$$

4.3 Machinery Fixed Costs

One of the most important costs influencing profit in farming operations is the cost of owning and operating machinery. Machinery costs are one of the few costs that good management can minimize and learning how to accurately estimate machinery costs will aid in cutting costs.

Machinery fixed costs are those that depend more on how long a machine is owned rather than how much it is used. Machinery fixed costs include depreciation, taxes, housing, insurance, and interest.

4.3.1 Depreciation

As a cost, depreciation means a loss in the value of a machine due to time and use and is frequently the largest of all costs. Machines depreciate, or lose value, for several reasons, including:

Age: Although model changes may result in little difference in the function of a machine, the newer machine is worth more than an old one.

Wear: The more a machine is used, the greater it wears. As a result, the ability to function like new may be reduced or the frequency of breaking down increases, meaning it has lost its reliability.

Obsolescence: If there has been a major model change or a machine no longer has enough capacity, its value may be greatly reduced, although it may not be worn out. New machine concepts may also be introduced which may obsolete existing similar machines.

There are several different ways to calculate depreciation. The methods used most frequently are:

1) *Straight-line depreciation:* With this method, an equal reduction of value is used for each year the machine is owned. This method can be used to estimate costs over a specific period of time.

2) *Sum-of-the-year-digit depreciation:* It is an accurate method of estimating the true value of a machine at any age because the annual depreciation rate decreases as the machine gets older. The sum-of-the-year-digit method is better than the straight-line method for estimating the true on-farm value of a machine due to a higher depreciation rate during the early years of machine life.

3) *Declining-balance depreciation:* The declining-balance method better reflects the actual value of a machine at any age than either the straight-line method or the sum-of-the-year-digits method. With the declining-balance method, a machine depreciates a different amount each year, but the annual percentage of depreciation is the same. For instance, Figure 4.3 shows an annual depreciation of 20 percent of the remaining value. By using a first-year correction factor, the declining-balance depreciation method will give a fairly accurate estimate of the remaining value for tractors or equipment.

The method used in this program to calculate machinery fixed cost is the declining-balance depreciation method. The formula for this method is listed below:

$$RV = C \times \left(1 - \frac{r}{L}\right)^y$$

Where RV = Remaining Value

C = Cost

r = Rate of depreciation compared to the straight-line method.

L = Life, years

y = Age of machine, years

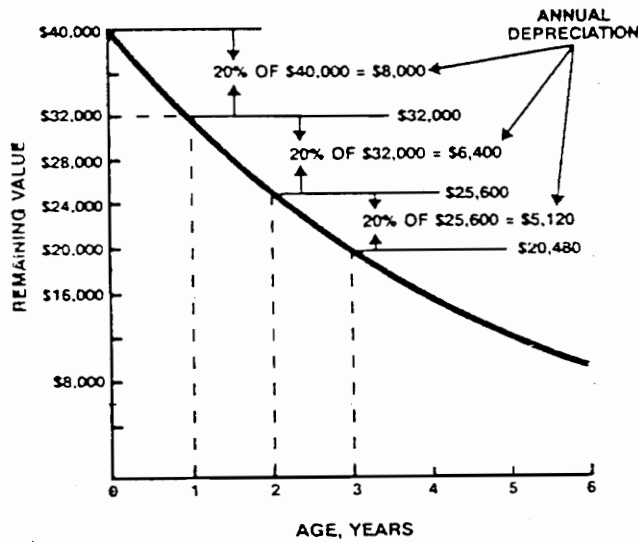


Figure 4.3 Declining-Balance Depreciation

The declining-balance method works on the basis that whatever value a machine has at the beginning of the year, it will be worth a fixed percentage of that value one year later. In actual practice, the first-year depreciation is considerably higher, percentage-wise, than in later years. To provide a more accurate method for estimating the value of the machines, a first-year correction factor is added to the declining-balance formula. The modified formula is given below:

$$RV = \text{list price} \times RV1 \times RV2^Y$$

In this formula, the correction factor for the first year is RV1. The annual depreciation factor is RV2. ASAE Standard (1992) lists these factors for tractors, combines, and other farm equipment. For example, the first year correction factor for all tractors is 0.64, and the annual depreciation factor for all tractors is 0.94. So the depreciation costs for all tractors may be calculated with the following formula:

$$RV = \text{list price} \times 0.64 \times 0.94^Y$$

$$\text{Depreciation} = \text{Purchase price} - RV$$

A 120 horsepower tractor that has a list price of \$65500.00, and was purchased at 90% of its list price is \$58950.00. Then its remaining value at the beginning of the second year is:

$$RV = \$65500.00 \times 0.60 \times 0.935^1 = \$36745.50$$

Then the depreciation of the first year is:

$$\text{Depreciation} = \text{Purchase price} - RV = \$58950.00 - \$36745.50 = \$22204.50$$

4.3.2 Other Fixed Costs

Other fixed costs considered by this program are housing, insurance, and interest.

This program uses HII as abbreviation for these three costs.

Housing: There is a tremendous variation in farmers' use of housing for agricultural machinery storage. Experts agree that if machinery is not stored, more repairs will be needed, machines will depreciate faster and, in general, higher ownership costs will result. For this reason, a charge is made for housing by this program whether it is actually provided or not. Typical annual costs for providing housing, including a service or repair shop, will average one to two percent of the remaining value of the machine. In this program, the user can specify the housing rate.

Insurance: Insurance policies are usually carried on more expensive machines while the risk is usually assumed on the simpler, less expensive machines. The annual charge for insurance can be specified by the program user as a percentage of the remaining value of the machine.

Interest: A large expense item for agricultural machinery is interest. It is a direct expense item on borrowed capital. Even if cash is paid for purchased machinery, money is tied up that might be available for use elsewhere in the business.

$$\text{HII} = \text{remaining value} \times (\text{housing rate} + \text{Insurance rate} + \text{Interest Rate})$$

For example, if the program user specifies the housing rate to be 1.5%, insurance 0.5%, and interest rate 10%, and a tractor is purchased at a price of \$58950, the HII cost for the first year is:

$$\begin{aligned} \text{HII} &= \text{remaining value} \times (\text{housing rate} + \text{Insurance rate} + \text{Interest Rate}) \\ &= \$58950 \times \left(\frac{1.5}{100} + \frac{0.5}{100} + \frac{10}{100} \right) = \$7074 \end{aligned}$$

4.4 Machinery Variable Costs

Machinery variable costs considered in this program are repair and fuel costs. These costs are sometimes called operating costs because they are directly proportional to the amount of use.

4.4.1 Estimating Repair Cost

Repair costs, usually considered operating costs, are other components of machinery costs. The more a machine is used, the greater is its need for repairs. However, some machine components have surfaces that rust, rot or otherwise deteriorate over the years. Repair costs caused by deterioration, though not necessarily affected by the amount of use, are still considered an operating cost.

Repair costs should be considered a necessary and important part of machinery ownership. With any machine there are four main types of repairs. These types are 1) routine wear, 2) accidental breakage or damage, 3) repairs due to operator neglect, 4) routine overhauls.

Usually repair costs are related to how much a machine has been used. Therefore, before estimating how much to expect in the way of repair costs, it is necessary to set some limitations on the total maximum life a machine can be expected to continue operating. We can then develop some guidelines for repair cost estimates. Table 4.3 lists some estimated mechanical lives from ASAE Standard (1987).

Table 4.3 Estimated Mechanical Life

Machine	Life, Hours
All Wheel Type Tractors	12,000
Crawlers	16,000
Self-Propelled Combine	3,000
LG SQ Balers	3,000
Tillage Equipment, Mowers	2,000
Planter, Drill, LG Rnd Balers	1,500
SM SQ Balers, Rakes	2,500
SP Forage Harvesters	4,000

Repair costs consist of all expenditures for parts and labor for repairs made in a shop or on the farm. In the case of older equipment an estimate of deferred repair costs should be included. It is difficult to accurately predict repair costs for a specific machine. Repair costs will vary from one geographical section of country to another because of differences in soil, crop, climate and operators. Repair costs can be estimated for any machine with the following formula:

$$TAR = \text{List price} \times RC1 \times \left(\text{Hours} / 1000 \right)^{RC2}$$

Where: TAR = Total accumulated repairs

Hours = Hours the machine has been used

RC1, RC2 = Constant factor for calculating machinery repair costs. They vary from machine to machine.

The repair cost formula should not be used when total hours exceed expected life.

The program uses the above formula to calculate total accumulated repairs. The constant factors RC1, RC2 for tractors, combines, and other farm equipment can be found in the ASAE Standard (1992).

As an example, the constant factors RC1 and RC2 for tractors may be 0.007 and 2.00 respectively. If the list price of the tractor is \$65500.00, and annual use of the tractor is 632 hours per year, the repair cost of this tractor for the first year is:

$$\begin{aligned} \text{TAR} &= \text{List price} \times \text{RC1} \times (\text{Hours} / 1000)^{\text{RC2}} \\ &= \$65500 \times 0.007 \times \left(\frac{632}{1000}\right)^{2.0} = \$183 \end{aligned}$$

4.4.2 Estimating Fuel Costs

The most accurate methods for estimating fuel costs are accurate records on similar machines and operations. However, in cases where such records are not available, it is relatively simple to estimate fuel consumption costs for specific operations. Estimating these costs is possible because the amount of fuel consumed is directly related to the amount of energy expended.

Average fuel consumption for tractors: For most farming operations, a tractor will operate at an average of approximately 55 percent of its maximum power during the year. This figure is based on the work by Bowers (1987) that measured the percentage of time the tractor operated at each power level. Multipliers based on this work have been determined to estimate fuel requirements and are listed in Table 4.4.

Table 4.4 Average Fuel Consumption for Different Types of Tractor Engines

Engine (Fuel Type)	Average Fuel Consumption (Gallons Per Hour Per Maximum PTO HP)
Gasoline	0.068
Diesel	0.051
LP-Gas	0.080

For a 120 horsepower diesel tractor, the average fuel consumption is $0.051 \times 120 = 6.12$ gallons per hour. If the tractor is used 632 hours per year, the annual fuel consumption of this tractor is 3867.84 gallons. If diesel costs \$1.00 per gallon, the annual fuel cost for this tractor is \$3867.84.

Average fuel consumption for combines: Calculating fuel consumption for combines is accomplished the same way as calculating fuel consumption for tractors. In this program, combines and tractors are assumed to have the same average fuel consumption rate. The method for calculating fuel cost for combines is the same as for tractors.

4.5 Optimization Procedures

There are nine tractor sizes (60, 80, 100, 120,140, 160, 180, 200, and 240 horsepower) and four combine sizes (140, 180, 215, and 260 horsepower) available in this program. It is difficult to evaluate all combinations to find an optimum one. In order to reduce the optimization time, this program limits tractor number and sizes, and combine number and sizes. The maximum tractor number is six, and these tractors can only be two sizes from 60 horsepower to 240 horsepower. The maximum number of combines is three, and these combines can only be one size from 140 horsepower to 260 horsepower. By adding this limitation there are still over 40 combinations of tractor and combine sizes. This program evaluates these machinery sets and reports the eight lowest-cost machinery sets to the user.

To find the least cost machinery set, a first trial is made by setting the size of the large tractor to 240 horsepower, the largest available in the program. The small tractor is set to one tractor size increment less than the large tractor size, and the size of combines is set to 260 horsepower, the largest in the program. With this set of machinery, the input data, and stored data files, the field operations are scheduled and the costs for machinery, labor, and timeliness are calculated. These costs are summed to get the total average annual machinery cost.

The size of the small tractors and the combines are decreased and the work schedule and costs are then re-computed. Sizes of the small tractors and combines continue to be decreased until the total annual cost increases due to increased timeliness

costs. Combinations of small tractor and combine sizes are tried until the least cost machinery set has been found. Table 4.5 is a copy of the screen showing the costs in dollars per acre for the different machinery sets evaluated for an example farm with the large tractor fixed at 240 horsepower. The XXXX's on the screen indicate a machinery set which is not able to complete the operations within a calendar year, a tractor is of insufficient size to pull an implement, or an operation could not be completed by the latest finish date listed in the input data.

Table 4.5 Optimization Screen

<u>Searching for an optimal set of machinery:</u>				
Small Tractor, HP	Large 1:	240 hp	tractor	
60	XXXX	XXXX	XXXX	2 Operator(s) Small planters
80	65.26	59.26	63.95	
100	67.67	61.51		Lowest Cost = \$59.26
120		62.82		240 HP TRACTOR = 1
140		63.59		80 HP TRACTOR = 1
160	70.91	64.41		215 HP COMBINE = 1
180		65.35		
200			68.47	
240				
	140	180	215	260
				Combines hp

Next in the optimization, the size of the large tractors is reduced one increment, in this case to 200 horsepower, and the procedure is repeated. The size of the large tractor is reduced until the least cost increases.

For final trials, the least cost is determined with all tractors the same size. Thus, the total cost is determined for all possible size combinations of the two tractor sizes and combine sizes which could result in the least cost.

Chapter 5

Modifying The Program

This chapter discusses how necessary modifications were made to this system for Virginia agriculture. The software consists of three parts. They are 1) the executable file, 2) stored data files (jtk files), and 3) the farm data file.

The first component of the system is the executable file. The source code was written in Microsoft C version 7.0 and has five modules containing more than 15,000 lines. This part of the program implements the methodology of machinery selection and optimization procedures.

The second component of the system are the stored data files (.jtk files). These provide very important data sets for the first component. For example, the weather probability files provide data necessary for calculating favorable field work days, the cost factor file provides factors used as constants to calculate machinery depreciation, and operating costs. The machinery productivity file indicates how to match sizes of implements to tractor power and provide a productivity estimate for each matched combination.

The third component of the system is the farm data file which varies from farm to farm. This file is created by the first part of the program during the interactive period with the program user. Within this file, information specific to a farm such as required field

operations, cropping systems, and some current economic factors are stored. These data are entered by the program user and are stored in this file for later use.

Methodologies and optimization procedures discussed in chapter four do not relate to a specific geographic location. Procedures can be used to select optimum machinery sets for states other than Illinois. The first component of the system, therefore, does not require modification. It can be used directly under Virginia weather and soil conditions. The first component of the system also serves as the interface for the program user and does not depend on geographic location. The third component of the system is created by the first component and is related to a specific farm. The program user establishes this file with farm-specific data and economic situations. The only part of the system requiring modification is the second component - the stored data files.

5.1 Work Day Probability Files

Within the program there are six jtk files related to work day probabilities. They are “wpnames.jtk” and files “prob1.jtk” through “prob5.jtk.”

Wpnames.jtk is the file used to match work day probability files prob1.jtk - prob5.jtk to geographic locations. The locations considered within this program are southern, central, and northern Illinois and two other locations which can be specified by the program user. Allowing program users to provide their own workday probability files allows the program to be applicable to states other than Illinois. The original file

“wpnames.jtk” is listed as Table 5.1. Probability file prob1.jtk is associated with Central Illinois region, prob2.jtk with Southern Illinois and so on.

Table 5.1 File Listing -WPNAMES.JTK

WPNAMES
prob1.jtk
Central Illinois
prob2.jtk
Southern Illinois
prob3.jtk
Northern Illinois
prob4.jtk
New State 1
prob5.jtk
New State 2

Prob1.jtk - prob5.jtk are files used by the program to estimate favorable field work days. For example, prob2.jtk stores the work day probability data for southern Illinois (Appendix A, Table A6). The probability level of these files is set to be 5 out of 6 years (83.3% of time). For example, from November 7 to November 20, only 5.6 or less days out of 14 are expected to be feasible for field operations with 83% confidence.

The work day probability files were modified because weather conditions of Virginia are different than those of Illinois. The modified version of the program still provides users five options in term of probability or weather risk levels. They are:

- 1) 85.7% of time (means number of favorable days available 6 out of 7 years)
- 2) 71.4% of time (means number of favorable days available 5 out of 7 years)
- 3) 57.1% of time (means number of favorable days available 4 out of 7 years)

4) 50% of time (7-year average)

5) 42.9% of time (means number of favorable days available 3 out of 7 years)

The weather data used to create these five probability files is from Virginia Agricultural Statistics (1986) and (1992) (Appendix A, Table A7). From these data, five data groups with different risk levels were derived (Appendix A, Table A8), and their corresponding probability files were created using the method discussed in chapter four. The file “prob50.jtk” is listed in the Appendix A, Table A9.

Modified “wpnames.jtk” file is listed below (Table 5.2).

Table 5.2 Listing of the Modified WPNAMES.JTK File

WPNAMES
prob85.jtk
6 out of 7 years
prob71.jtk
5 out of 7 years
prob57.jtk
4 out of 7 years
prob50.jtk
7 years average
prob42.jtk
3 out of 7 years

In order to make the program display properly due to the modifications made to the files “wpnames.jtk” and “prob1.jtk - prob5.jtk”, the main module of the source code s10.c was modified. The modified portion of the source code is listed as below:

```
/* Line 167 - 193 */  
  
char *SLMENU1[6], *str;  
char file[30];
```

```

static int h_pos, v_pos=0;
for (i=0; i<5; i++)
    {
    if ( (str = alloca(40)) == NULL )
    {
    beep(1);
    return (0);
    }
    rmvdot(file, wpfiles[i].des, 30);
    strcpy(str, file);
    SLMENU1[i] = str;
    }
if ( (SLMENU1[5] = alloca(40)) == NULL )
    {
    beep(1);
    return (0);
    }
strcpy(SLMENU1[5], "Return");
out_msg(11,4,"Select Workday Probability File");
while ( !done )
{
if (mouse_installed)
    select = m_v_menu(v_pos,3,5,SLMENU1,6);
else
    select = v_menu(1,v_pos,3,5,SLMENU1,6);
}

```

5.2 Machinery Related Data Files

There are four stored jtk files (cfactors.jtk, listoper.jtk, machprod.jtk, harvprod.jtk) that store machinery information. They work together to provide necessary information for calculating machinery fixed and variable costs, estimating machinery capacity, defining tractor and combine sizes available within the program, and defining all possible operations commonly used for planting crops such as corn and soybeans. Relationships

among these .jtk files are demonstrated in Fig. 5.1. This figure will be explained in more detail later.

The file “listoper.jtk” is used to store field operations which are commonly considered to be the possible operations for planting corn, soybeans, wheat, oat, and sorghum in Illinois (Appendix A, Table A10).

The file “cfactors.jtk” is used to provide the constant factors (RV1, RV2, RC1, RC2) for calculating machinery fixed and variable costs for tractors, combines, and implements defined in the file “listoper.jtk”.

The file “machprod.jtk” defines available tractor sizes. Implements corresponding to those field operations defined in the file “listoper.jtk” are also defined. This file also matches the sizes of the implements to tractor sizes and provides the estimated productivity of each tractor/implement combination.

The file “harvprod.jtk” defines available combine sizes and the sizes of corn heads and grain platforms. These are matched to combine sizes, and the productivity values for these combinations of combine/ corn head and combine/ grain platform are estimated.

5.3 Operation List File — LISTOPER.JTK

Corn, soybeans, wheat, oat, and sorghum are commonly planted crops in Illinois. The file “listoper.jtk” lists all possible field operations commonly considered to be applicable for these five crops. In this file, thirty field operations were considered to be

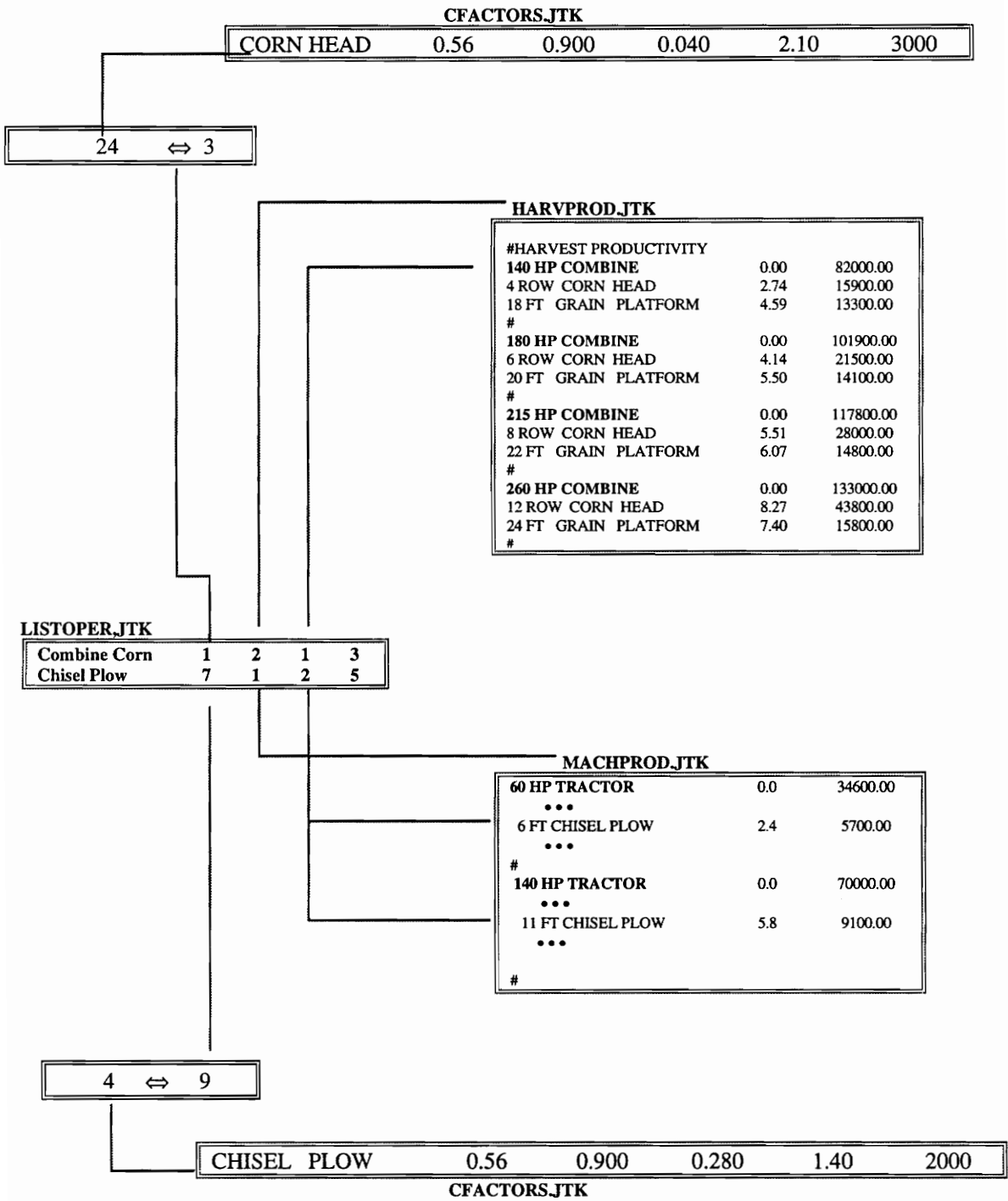


Fig. 5.1 Relationship Among the Machinery Related JTK Files

necessary for these five crops. These thirty operations are listed in Appendix A, Table A10. Columns in the table are explained below:

1) The first column in the file lists the operation names.

2) The second column assigns each field operation with a number. When a user specifies a field operation, only an operation number needs to be entered. For example, when the program asks the user to specify a field operation, and the number 8 is entered, the program knows that the user is referring to the operation DISK HARROW.

3) The third column is the power unit column that indicates the power unit for each field operation. The number of “ 1 ” indicates that the operation is performed by a tractor and an implement, the number of “ 0 ” indicates the operation is performed by a combine and an attachment.

4) The fourth column is the matching indicator column that indicates how to match implements to tractors and attachments to combines for this field operation. It serves as a linker among the machinery data files. It is used with files “machprod.jtk” and “harvprod.jtk” to provide completed matching, productivity, and price information for the program.

5) The fifth column was designed to assign a priority to each field operation. It is not ready for use for this version.

The original file contains thirty field operations considered to cover all possible or necessary field work for planting corn, soybeans, wheat, oat, and sorghum in Illinois. This

file must be modified if the farmer plans to grow crops not covered by the original file or if a different tillage system is used other than the one supported by the original file.

This program can only handle thirty field operations. If a new operation was desired, the old one would be deleted, and the operation number of the deleted one would be assigned to the new operation. The program is also limited to deal with five crops. Operations from 1 to 5 are reserved for harvesting operations of these five crops, and operations from 21 to 26 are reserved for planting operations of these five crops.

The objective of this work was to adapt the methodology of machinery management used by this program and make some appropriate modifications to the program to make it applicable to Virginia farm conditions. The first step was to run the program with data for a hypothetical farm (to be discussed in detail in chapter six). The hypothetical Virginia farm has four crops. They are corn, wheat, full season soybeans, soybean double cropped with wheat. Full season soybean and double crop soybean are considered two different crops here and are treated separately. The operations that were added to this file are listed below:

Combine Soybeans/FS (FS means Full Season)

Combine Soybeans/DC (DC means Double Cropping)

Rotary Mower Stalks

Spread Seed

Plant Soybeans/FC

Plant Soybeans/DC

In order to add these six operations to the files, six operations were deleted from the file. In this case, Combine Soybeans/FS replaces Combine Soybeans, Combine Soybeans/DC replaces Combine Oats because oats were not considered by the hypothetical farm, Rotary Mower Stalks replaces Subsoiler, Spread Seed replaces Paraplow, Plant Soybeans/FS replaces Plant Soybeans, and Plant Soybeans/DC replaces Plant Oats. The modified listoper.jtk is listed in the Appendix A, Table A11. Modifications made to other parts of this file will be discussed in later sections.

5.4 Machinery Cost Factor File - CFACTORS.JTK

In this file cost factors for tractors, combines, implements, and attachments are stored. The program can automatically search this file whenever it needs these factors to calculate machinery depreciation and repair costs. The file is listed in Appendix A, Table A12. Columns in the table are explained below:

- 1) The first column lists names of implements, attachments, combines, and tractors available within this program.
- 2) The second column lists cost factors called RV1 for each machine. It is one of the two cost factors used to calculate machinery depreciation.
- 3) The third column lists the second depreciation factor for each machine. It is called RV2. RV1 and RV2 are the two factors needed to calculate machinery fixed costs.
- 4) The fourth column lists a cost factor called RC1 for each machine. It is one of the two cost factors used to calculate machinery repair costs.

5) The fifth column lists the second factor for calculating machinery repair costs. It is called RC2.

6) The sixth column lists hours of life for each machine. This factor was used to calculate machinery repair costs by the former version, but is not used in this version due the use of a different formula.

The order of operation names cannot be changed by the user. Each operation name and the cost factor following it in the same line of this file corresponds to one or more operations in the file listoper.jtk . The relationship between these two files is shown in Table 5.3:

Table 5.3 Relational Table Between CFACTORS.JTK and LISTOPER.JTK

Line # of implement in cfactores.jtk		Line # of operation in listoper.jtk	Line # of implement in cfactores.jtk		Line # of operation in listoper.jtk
1	↔	Tractor	13	↔	23,25,26
2	↔	6	14	↔	10
3	↔	7	15	↔	11
4	↔	8,14	16	↔	12
5	↔	9	17	↔	20
6	↔	13	18	↔	27
7	↔	21,22,24	19	↔	28
8	↔	18	20	↔	29
9	↔	19	21	↔	30
10	↔	16	22	↔	Combine
11	↔	16	23	↔	1
12	↔	17	24	↔	2,3,4,5

When calculating costs for field operation PLANT CORN, for example, the program needs cost factors RV1, RV2, RC1, and RC2 for corn head to compute depreciation and accumulated repair costs of the corn head. The program first checks the file “listoper.jtk” to find the line number of the operation PLANT CORN that is 21. The program then knows that the seventh line of the file “cfactors.jtk” contains these cost factors for the implement for performing PLANT CORN according to the relationship listed in Table 5.3.

The cost factors given by the original file cfactors.jtk were obtained from ASAE Standard (1987). This file has inter connections with the file listoper.jtk. If listoper.jtk is changed, cfactors.jtk must change accordingly. The relationship between modified files listoper.jtk and cfactors.jtk must follow Table 5.3. As was mentioned in the previous section, six operations in the file listoper.jtk were replaced. The modified cfactors.jtk file is listed in Appendix A, Table A4. As an example, SUBSOILER was replaced by ROTARY MOWER STALKS. This operation is the 10th line in the file listoper.jtk. Cost factors for rotary mower stalks are $RV1= 0.56$, $RV2=0.90$, $RC1=0.32$, $RC2=2.10$, $life=1500$ hours. According to Table 5.3, the 14th line in the file cfactors.jtk should be changed with these new factors.

5.5 Combine File - HARVPROD.JTK

The file harvprod.jtk is used by the program to define available combine sizes, match sizes of attachments to these combine sizes, and provide the estimated productivity

value for each combine/attachment combination. It also provides the list price for each attachment and combine. Two kinds of attachments are considered by this program for harvesting operations. They are row corn head for harvesting corn, and grain platform for harvesting soybeans, wheat, oat, and sorghum. Four combine sizes considered within this program are 140, 180, 215, and 260 horsepower. The contents of this file are listed in Appendix A, Table A13.

The first column of this file lists an appropriate sized corn head and grain platform attachments for a combine. These are the only two kinds of attachments available within this program for harvesting.

The second column lists the estimated productivity value for each combine/attachment combination. For example, a combine with 260 horsepower has sufficient power for a 12 row corn head, or a 24 ft grain platform. The productivity of each combine is set to zero because each combine cannot harvest the crops by itself.

The third column lists the list prices for these combines and attachments. These list prices are used to calculate fixed costs and repair costs for combines and attachments.

The third and fourth columns of the file listoper.jtk indicate how to match implements to tractors and attachments to combines. Table 5.4 lists a portion of the file listoper.jtk. The number of “2” in the third column of listoper.jtk tells the program that this operation is a harvesting operation and should be implemented by a combine, and the matching information is stored in the file harvprod.jtk. Once the file which stores the

matching information is determined, the number in the fourth column will tell the program where in the file to find the matching information.

Table 5.4 Portion of the File LISTOPER.JTK

COMBINE CORN	1	2	1	3
COMBINE SOYBEANS	2	2	2	1
COMBINE WHEAT	3	2	2	2
COMBINE OAT	4	2	2	3
COMBINE SORGHUM	5	2	2	1

For example, consider the operation number 1, COMBINE CORN. Machinery information for this field operation is stored in the file harvprod.jtk, because the number in the third column of this operation is 2. The number in the fourth column in the file listoper.jtk for this operation is 1. This means that the first lines under all available combine sizes in the file harvprod.jtk (Fig. 5.1) lists the attachments (4-row corn head, 6-row corn head etc.) that can be used to perform this operation , their sizes, and productivity values. For the operation COMBINE CORN, corn heads are the attachments for harvesting corn. The 4-row corn head is matched to a 140 horsepower combine. The productivity of this combination is 2.74 acres per hour. The 180 horsepower combine is matched with a 6-row corn head, and the productivity of this combination is 4.14 acres per hour (Appendix A, Table A13).

There are three reasons one might modify the file harvprod.jtk. First, productivity values for some or all of the combine/attachment combinations may require modification.

For example the productivity value of a 4-row corn head mounted on a 140 horsepower combine is 2.74 acre per hour in the original harvprod.jtk file. But in a specific farm, the productivity of this combination may be higher or lower than 2.74.

The second reason to modify this file is to input another attachment to perform harvesting operations not present in this file. In this case, the corn head or the grain platform would be deleted because this program can only handle two kinds of attachments. Sizes of the newly added attachments would need to be matched to the available combine sizes and productivity values would need to be estimated.

The third reason to modify this file may be to choose combine sizes other than those made available. Once the combine size is changed, corresponding attachment sizes and productivity values should also be checked and properly changed.

For the hypothetical farm to be detailed in chapter 6, a corn head is used to harvest corn, and a grain platform is used to harvest soybeans and wheat. New attachments, therefore, would not need to be added to this file. Combine sizes are the same, also, but productivity values required modification.

As was discussed in chapter four, the methodology used to match attachment sizes to combine power was given in the ASAE Standard (1992). An assumption is made that this matching is applicable to Virginia. The productivity of a 4-row corn head mounted on a 140 horsepower combine was given to be 2.76 acres per hour by the original file. But the productivity value for the same machinery combination for a typical Virginia farm was considered to be only 1.0 acre per hour by a Virginia farm management

agent (Sturt, 1994). Differences between them are due to the different soil type, weather conditions, and terrain. The productivity values of these four corn head sizes were adjusted by sample ratios referenced to the first entry and are shown in Table 5.5. The same procedure was employed to derive productivity values for the four grain platforms. The modified harvprod.jtk is listed in Appendix A, Table A2.

Table 5.5 Productivity Values of Corn Head

Combine Power	Corn Head Sizes	Productivity, Illinois	Productivity Virginia
140	4-Row Corn Head	2.76	2.76/2.76=1.00
180	6-Row Corn Head	4.14	4.14/2.76=1.50
215	8-Row Corn Head	5.51	5.51/2.76=1.99
260	12-Row Corn Head	8.27	8.27/2.76=2.99

5.6 Tractor and Implement File - MACHPROD.JTK

The file machprod.jtk is used by the program to define available tractor sizes, match sizes of implements to these tractor sizes, and provide the estimated productivity value for each tractor/implement combination. It also provides the list price for each available implement and tractor. Nine tractor sizes are considered within this program. The tractor sizes vary in increments of 20 horsepower, from 60 to 240 horsepower. A set of tillage implements are matched to each tractor size. The contents of this file is listed in Appendix A, Table A1.

The first column of this table lists implements under a tractor size considered to be sufficient to pull these implements. For example, the 60 horsepower tractor has sufficient

power to pull a 2*16 moldboard plow, 6 ft chisel plow, and a 100 horsepower tractor can pull a 4*18 ft moldboard plow, 8 ft chisel plow etc.

The second column lists the estimated productivity value for each tractor/implement combination. For example, the productivity for a 2*16 moldboard plow pulled by a 60 hp tractor is 1.47 acres per hour, a 4*18 ft moldboard plow pulled by a 100 horsepower tractor is 2.47 acres per hour. If a tractor does not have sufficient power to pull an implement, the productivity value is set to be 0.00. For example, for the 60 horsepower tractor the productivity value for knife application and combination tool are set to 0.0, which means the program will not allow the 60 horsepower tractor to be used for knife application and combination tool.

The third column provides the list price for each tractor and implement. These list prices were used by the program to calculate machinery fixed costs and repair costs. A list price of \$0.00 is used for a machine assumed not to be owned but made available at no charge. This often occurs with fertilizer applications and sprayers. For such operations, costs are estimated only for use of a tractor.

Relationships exist between listoper.jtk and machprod.jtk files. The third and fourth columns in the file listoper.jtk tell the program where to find information on how to match a tractor with appropriate implement sizes for each field operation. Table 5.6 lists a portion of the file listoper.jtk. The number in the third column indicates that this operation is performed by a tractor and a implement and tells the program that detailed

information is stored in the file machprod.jtk. Once the file is determined, the figure in the fourth column tells the program where in the program to find matching information.

For example, the operation DRILL WHEAT has an operation number of 23 (column 1) and machinery information for this field operation is stored in MACHPROD.JTK, because the number in the third column for this operation is one. The number in the fourth column is 12. This means that the 12th line under each tractor size in machprod.jtk lists the appropriate implement size matched to the tractor for this operation, and provides the estimated productivity for this operation.

Table 5.6 Portion of the File LISTOPER.JTK

SPRAY PESTICIDE	17	1	11	1
ROW CULTIVATE	18	1	7	5
ROTARY HOE	19	1	8	1
COMBINATION TOOL	20	1	16	4
PLANT CORN	21	1	6	2
PLANT SOYBEANS	22	1	6	3
DRILL WHEAT	23	1	12	4
DRILL OAT	24	1	12	1

For a 60 horsepower tractor that can pull a 10 ft drill to accomplish the field operation DRILL WHEAT, its the productivity value is 3.15 acres per hour. A 140 horsepower tractor can pull a 15 ft drill to accomplish the field operation DRILL WHEAT, and its productivity value is 6.5 acres per hour, and so forth.

The first change to file “machprod.jtk” could be productivity values for some or all of the tractor/implement combinations. For example, the productivity value of a 6 FT

chisel plow pulled by a 60 horsepower tractor is 2.40 acres per hour in the original machprod.jtk file. But in a specific farm, the productivity of this combination may be higher or lower than 2.40 acres per hour.

The second reason to modify this file is to input another implement to perform an operation not presented in this file. In this case, one implement would be deleted from this file because this program can only handle twenty types of implements. Sizes of the newly added implements would need to be matched to the available tractor sizes and productivity values would need to be estimated. When the file “machprod.jtk” is changed, the file “listoper.jtk” also requires modification.

The third reason to modify this file may be to choose tractor sizes other than those made available by the program author. If the tractor sizes are changed, corresponding implement sizes and productivity values should also be checked and properly changed.

For the hypothetical farm to be detailed in chapter 6, available tractor sizes were not changed, but productivity values of some implements required modification (Sturt, 1994) and two new implements were added that were not included in the original machprod.jtk file.

New implements added were rotary mower for mowing corn stalks and seed spreader for spreading corn seeds. As was discussed previously, two other implements must be deleted from the file in order to add these two new implements. In this case, the subsoiler and paraplow were deleted because these two implements were not needed for the hypothetical farm. The file listprod.jtk was also properly modified accordingly to

replace subsoiler with rotary mower stalks and paraplow with spread seed. Operation numbers, power units, and matching indicators (column 4 of the file listoper.jtk) were unchanged. The matching indicators for rotary mower stalks and spread seed are 13 and 14 respectively. This means the 13th and 14th lines under each tractor size in the file machprod.jtk require modification. The method used to modify the productivity values of the implements are the same as discussed in the last section. The modified machprod.jtk is listed in Appendix A, Table A1.

Chapter 6

Case Study and Discussion of the Results

A case study was performed to evaluate the modified version of the Farm Machinery Selection Program. The conditions chosen were representative of typical farms in Eastern Virginia.

6.1 The Hypothetical Farm

To illustrate and evaluate the use of the program, a hypothetical farm with 400 acres of corn, 300 acres of full season soybeans, and 300 acres of soybeans double cropped with wheat was created. Here, wheat is planted in the fall after soybean harvest, and wheat is harvested in the spring followed by soybean planting. The cropping program and required field operations are listed below in Table 6.1 and required field operations are listed in Table 6.2.

Table 6.1 Crops Grown in the Hypothetical Farm

	Acres	Land Number
Corn	400	0
Soybeans, Full Season	300	1
Soybeans, Double Cropping with Wheat	300	2
Wheat, Double Cropping with Soybeans	300	2

Table 6.2 Required Field Operations for the Hypothetical Farm

Crop	Required Field Operations
Wheat	Disk harrow Drill wheat Fertilizer application Combine wheat
Corn	Spread covercrop seed Disk seed in Plant corn - No Till Fertilizer application Spray pesticide Combine corn Rotary mower stalks Disk harrow
Soybean - Full Season	Disk harrow Fertilizer application Chisel plow Incorp. chemical with Disk Plant Soybeans Spray herbicide Spray insecticide Combine soybeans
Soybean - Double Cropping with Wheat	Plant soybeans - No Till Spray herbicide Spray insecticide Combine soybeans

6.2 Assumptions

The assumed optimum dates of planting and harvesting for each crop are listed in Table 6.3:

Table 6.3 Optimum Planting and Harvesting Dates for Each Crop

	Planting Dates	Harvesting Dates
Corn	3/30 --- 4/15	9/01 -- 9/20
Wheat	10/25 -- 11/05	6/15 -- 7/01
Soybeans, Full Season	5/15 -- 5/30	10/25 -- 11/15
Soybeans, Double Crop	6/15 -- 7/01	10/25 -- 10/20

Other assumptions are:

- 1) The farm manager can purchase farm machines at 90% of their list prices.
- 2) The sum of the housing, interest, and insurance is 10% of the remaining value of the farm machinery.
- 3) The fuel price is \$1.00/gal.
- 4) The yield of corn is 120 bushels per acre, and the price of corn is 2.60 dollars per bushel. The yield of Soybeans is 35 bushels per acre and its price is 6.00 dollars per bushel. The yield for wheat is 60 bushels per acre and can be sold for \$2.85 per bushel.
- 5) If the crop is planted one day later than its latest assumed optimum planting date, a 1% yield reduction is assumed for corn, soybeans, and 0.25% yield reduction is assumed for wheat. If the crop is harvested one day later than its latest assumed optimum

harvesting date, a 1% yield reduction is assumed for soybeans, wheat, and 0.5% yield reduction is assumed for corn.

6.3 Case Study

The program provides three run options as discussed in chapter 3. Based on the information listed above, the program was first run with “run with optimizing” option. With this option, the number of tractors and the quantity that are large and small, the number of combines, and the number of operators are specified. After having required input data all entered, this program optimizes the size of the tractors and combines specified by the user, calculates annual use of each machine and machinery related costs, and schedules field operations for the user. For this analysis, the program was run several times with different numbers of tractors, combines, and operators, and then results were compared.

For the hypothetical farm, one to four tractors, one or two combines, two to six operators were selected in the combinations listed in Table 6.4. These machinery sets were evaluated to find the least-cost combination.

Table 6.4 Combinations of Tractors, Combines and Operators

Combinations	# of Tractors		# of Combines	# of Operators
	Large	Small		
1	1	0	1	2
2	1	0	1	3
3	1	0	1	4
4	0	1	1	2
5	0	1	1	3
6	0	1	1	4
7	1	0	2	3
8	1	0	2	4
9	0	1	2	3
10	0	1	2	4
11	1	1	1	3
12	1	1	1	4
13	1	1	2	3
14	1	1	2	4
15	1	1	2	5
16	2	0	1	3
17	2	0	1	4
18	0	2	1	3
19	0	2	1	4
20	2	0	2	3
21	2	0	2	4
22	2	0	2	5
23	2	1	1	3
24	2	1	1	4
25	2	1	1	5
26	2	1	2	4
27	2	1	2	5
28	2	2	1	4
29	2	2	1	5
30	2	2	2	5
31	2	2	2	6

6.4 Results and Discussion

The program was run thirty one times with the specified number of tractors, combines, and operators listed in Table 6.4. The work day probability was set to be 6 of 7 years (meaning that assumed good work days listed in the file “prob85.jtk” with a 0.86 probability can be expected). Optimization results are listed in Table 6.5. In operation, the program outputs eight lowest-cost machinery sets each time it is run. In the Table 6.5, only the lowest-cost machinery set (with specified number of tractors, combines, operators, and optimized sizes) for each run is shown.

By comparing results listed in Table 6.5, the lowest cost machinery set for the hypothetical farm is:

- Two tractors with the same size of 120 horsepower.
- One Combine with size of 260 horsepower
- Four operators with hourly paid salary
- Total machinery-related costs is \$82.15 per acre

The program schedules the field operations on a day-to-day basis, giving priority to the order that the operations are listed in the input data. For the optimum machinery set (two 120 hp tractors, one 260 hp combine, and 4 operators), field operations are scheduled as shown in Table 6.6.

For the hypothetical farm, the first field operation scheduled is COMBINE CORN which starts on September 1, and can be finished using one 260 hp combine on

Table 6.5 Optimization Results

Combination	Large Tractors		Small Tractors		Combines		Machinery Costs	Labor Costs		Timeliness Costs	Total
	#	Size	#	Size	#	Size		#	Costs		
1	1	240	0		1	260	70.92	2	7.32	89.52	167.76
2	1	200	0		1	260	67.76	3	7.47	9.09	84.32
3	1	200	0		1	260	67.76	4	7.47	9.09	84.32
4	0		1	240	1	260	70.92	2	7.32	89.52	167.76
5	0		1	00	1	260	67.76	3	7.47	9.09	84.32
6	0		1	200	1	260	67.76	4	7.47	9.09	84.32
7	1	200	0		2	260	81.93	3	7.47	9.09	98.49
8	1	200	0		2	260	81.93	4	7.47	9.09	98.49
9	0		1	200	2	260	81.93	3	7.47	9.09	98.49
10	0		1	200	2	260	81.93	4	7.47	9.09	98.49
11	1	160	1	160	1	260	71.60	3	7.79	4.59	83.99
12	1	120	1	120	1	260	69.16	4	8.62	4.38	82.15
13	1	160	1	160	2	260	85.77	3	7.79	4.59	98.15
14	1	120	1	120	2	260	83.32	4	8.62	4.38	96.32
15	1	120	1	120	2	260	83.32	5	8.62	4.38	96.32
16	2	160	0		1	260	71.60	3	7.79	4.59	83.99
17	2	120	0		1	260	69.16	4	8.62	4.38	82.15
18	0		2	160	1	260	71.60	3	7.79	4.59	83.99
19	0		2	120	1	260	69.16	4	8.62	4.38	82.15
20	2	160	0		2	260	85.77	3	7.79	4.59	98.15
21	2	120	0		2	260	83.32	4	6.62	4.38	96.32
22	2	120	0		2	260	83.32	5	6.62	4.38	96.32
23	2	160	1	140	1	260	78.19	3	7.81	5.02	91.03
24	2	120	1	100	1	260	73.75	4	8.69	4.38	86.81
25	2	120	1	100	1	260	73.75	5	8.69	4.38	86.81
26	2	120	1	100	2	260	87.91	4	8.69	4.38	100.98
27	2	120	1	100	2	260	87.91	5	8.69	4.38	100.98
28	2	120	2	100	1	260	79.58	4	8.69	4.38	92.65
29	2	120	2	100	1	260	79.58	4	8.69	4.38	92.65
30	2	120	2	100	2	260	93.64	5	8.69	4.38	106.71
31	2	120	2	100	2	260	93.64	6	8.69	4.38	106.71

Table 6.6 Work Schedule

Field Operations	Start Date	Finish Date	Calendar Date	Work Days	Acres
Combine Corn	9/1	9/17	17	11.4	400
Rotary Mower Stalks	9/3	9/17	15	10.0	400
Disk Harrow	9/17	9/27	11	6.7	400
Spreader Seed	9/27	10/21	7	4.0	400
Disk Harrow	10/3	10/12	10	6.7	400
Spray Pesticide	3/25	3/27	3	2.0	400
Apply Fertilizer	3/28	3/30	3	2.0	400
Plant Corn	4/3	4/10	8	5.3	400
Combine Soybeans/FS	10/25	11/5	12	7.8	300
Disk Harrow	4/6	4/23	8	5.0	300
Apply Fertilizer	4/23	4/25	3	1.5	300
Chisel Plow	4/25	5/14	20	10.9	300
Disk Harrow	5/14	5/23	10	5.0	300
Plant Soybeans/FS	5/23	5/29	7	5.0	300
Spray Pesticide	6/15	6/19	5	1.5	300
Spray Pesticide	7/15	7/16	2	1.5	300
Combine Soybeans/DC	11/6	* 11/17	12	7.8	300
Disk Harrow	11/6	11/17	12	5.0	300
Drill Wheat	11/6	* 11/21	16	4.6	300
Spray Pesticide	8/15	8/16	3	1.5	300
Spray Pesticide	7/16	7/18	3	1.5	300
Combine Wheat	6/15	6/26	12	7.8	300
Plant Soybeans/DC	6/15	6/26	12	4.0	300
Apply Fertilizer	3/28	3/30	3	2.0	300

“ * ” indicates a timeliness penalty occurs

September 17. Because the penalty date of late harvesting for corn was assumed to be September 20, there are no timeliness costs for this field operation. Calendar days for corn harvesting are 17 days (from Sept. 1 to Sept. 17), and this operation requires 11.4 days to finish with total area of 400 acres.

It is assumed the operator spends 50% of the time hauling and processing the grain. Thus, the number of hours per day the operator actually spends operating the combine is reduced. When two operators are available, the combine operates the full number of hours per day listed in the input data and the operation requires use of the two operators. Large variations exist in the time spent in unloading, hauling, and processing grain during harvest operations.

Each field operation starts on the date listed in the input data, unless an operator and machine are not available; in which case the start date for that operation is the first date that both an operator and a machine are available. Disk Harrow, for example, the field operation after the Rotary Mower Stalks in the corn land, was supposed to start on September 3. But since there is no operator or machine available at that time, this operation is then delayed and is performed on September 17.

For another example, field operation “Combine Soybeans/DC” is scheduled to start on November 6. The assumed optimum starting date for this field operation is October 25. It is delayed because the selected machinery set does not have enough capacity to start the operation on time. The finish date is therefore delayed to November

17 which is two days after its optimum finish date. So timeliness costs for this field operation would be expected.

As field operations are scheduled, the annual hours of use for each machine are accumulated. The fixed costs and variable costs for each machine are calculated as previously explained using the annual use, input data, and data from the stored files. The fixed and variable costs are summed and the results are used to calculate the cost per acre for each field operation (Appendix B).

If desired, the detailed costs for each machine are provided for each year up to 10 years of ownership. For the hypothetical farm, the costs of the combine and corn head are presented in Appendix B, Table B9. The program presents the costs of other machines in a similar manner (Appendix B, Table B8-B20).

The total machinery-related costs for the machinery set are given for the hypothetical farm (Table 6.7).

Table 6.7 Average Annual Machinery-Related Costs for the Hypothetical Farm

Cost	\$ / Year	\$ / Acre
Machinery Fixed Cost	52377.51	52.38
Fuel Cost	7223.10	7.22
Repair Cost	9554.99	9.55
	-----	-----
Total Machinery Cost	69155.62	69.16
Labor Cost	8618.33	8.62
Timeliness Cost	4378.29	4.38
	-----	-----
Total Cost	82152.23	82.15

The machinery fixed cost includes estimated depreciation, housing, interest, and insurance. The estimated fuel and repair costs are added to the fixed cost to get the total machinery cost. Labor cost is figured using the labor rates entered. Timeliness cost is calculated for the acres of any crop planted or harvested after the penalty dates specified. From the work schedule explained previously for the hypothetical farm, the “Combine Soybeans/DC” and “ Drill Wheat” operations are completed late. Thus, timeliness costs are calculated. The costs for machinery, labor, and timeliness are summed to provide an estimate of the total annual machinery-related cost for the optimum machinery set.

The program was then run with “run with complete optimization” option. With this option, the user does not need to specify the number of tractors, combines, and operators. The optimum machinery set found by this option is listed as the following with total machinery related costs of \$84.32/per acre:

- One tractor of size 200 horsepower
- One combine of size 260 horsepower
- Three operators
- The total machinery-related cost is \$84.32 / per acre

The lowest-cost machinery sets found with optimization option and with complete optimization option for the same hypothetical farm are different. The COMPLETE OPTIMIZATION option was not checked fully. The original program authors recommended that the complete optimization option be used as the first step to find machinery set. This machinery set may be close to the actual optimum one. Then the “ run

with optimization” option could be used to check the machinery sets that are close to the one found using “run with complete optimization” option in terms of the number of tractors, combines, and operators.

6.5 Model Sensitivity Analysis

A sensitivity analysis was conducted for this machinery selection model to illustrate the effects of several model inputs on the optimum machinery completion. As was discussed in chapter 5, the modified version provides five risk levels in terms of the work-day probability. This has a direct effect on selection of the optimum machinery set. The risk level used for the results obtained in the previous section is the lowest one among the five levels available within the program. In order to demonstrate how the weather affects the selection, the program was run with other risk levels. The program was run with the same procedure as discussed above under the other risk levels. The lowest-costs machinery sets were found as shown in Table 6.8:

Table 6.8 Optimization Results with Different Risk Levels

Risk Level	Large Tractors		Small Tractors		Combines		Machinery Costs	Labor		Timeliness	Total
	#	Size	#	Size	#	Size		#	Costs		
6 out of 7	1	120	1	120	1	260	69.16	4	8.62	4.38	85.15
5 out of 7	1	160	0		1	260	67.09	3	7.48	2.94	77.52
4 out of 7	1	160	0		1	260	65.18	3	7.79	2.64	75.61
Average	1	160	0		1	260	65.18	3	7.79	2.28	75.25
3 out of 7	1	140	0		1	260	64.25	3	8.06	0.88	73.18

As the risk level goes down, either the machinery capacity or total machinery related costs go down. For example, if the highest risk level (3 out of 7 years) was chosen, the optimum machinery set for the same farm would have much less capacity than the one obtained under lowest risk level (6 out of 7 years). Also, all required field operations could be completed on time. The total machinery related costs under highest risk level is nearly 10 dollars per acre lower than that under lowest risk level. The reason for this is that we can expect less suitable days for field work under the highest risk level.

Labor availability, as a type of farm resource, has another important effect on the machinery selection. The optimum machinery set for this hypothetical farm under the lowest risk level requires four operators (Table 6.8). However, the number of actual available operators may be less than four. In this case, other alternatives must be tried. Optimum machinery sets for the hypothetical farm under the lowest risk level were searched with a different number of available operators. Results are summarized in Table 6.9.

Table 6.9 Optimization Results with Different Number of Operators

# of Labor	Large Tractors # Size	Small Tractors # Size	Combines # Size	Machinery Costs	Labor Costs	Timeliness	Total
1							
2	1 160	1 160	1 260	71.12	7.79	16.33	95.24
3	1 160	1 160	1 260	71.60	7.79	4.59	83.99
4	1 120	1 120	1 260	69.16	8.62	4.38	82.15
5	1 120	1 120	1 260	69.16	8.62	4.38	82.15
6	1 120	1 120	1 260	69.16	8.62	4.38	82.15

Table 6.9 shows that when only one operator is available, the program cannot schedule the required operations within one year, and total machinery costs are too high to be accepted. When there are two operators, the timeliness cost runs as high as 16.33 dollars per acre. The optimal number of operators was found to be four. When available operators exceed four, total machinery related costs are the same because labor costs are hourly based.

The effect of varying the cropping area was less drastic. The program was run with five farm sizes (Table 6.10) to illustrate the effect of farm size on machinery selection. The sizes and cropping programs are listed in Table 6.10. Results of varying farm size are listed in Table 6.11.

Table 6.10 Five Farm Sizes

	Total	Corn	Soybean/FS	Wheat/Soybean
1	500	100	200	200
2	700	300	200	200
3	1000	400	300	300
4	1300	500	400	400
5	1500	500	500	500

Table 6.11 Optimization results with different farm sizes

Farm Size Acres	Large Tractors		Small Tractors		Combines		Machinery Costs	Labor		Timeliness	Total
	#	Size	#	Size	#	Size		#	Costs		
500	1	140	0		1	180	86.51	3	9.68	3.10	99.29
700	1	140	0		1	180	70.86	3	9.79	3.43	84.08
1000	1	120	1	120	1	260	69.16	4	8.62	4.38	82.15
1300	1	140	1	140	2	180	68.64	5	9.76	3.11	81.52
1500	1	140	1	140	2	260	71.29	6	7.77	2.10	81.16

The farm size has little effect on the total machinery related costs per acre, as illustrated in Table 6.11. It does, however have effect on the optimum machinery capacity requirements. For example, for the hypothetical farm, when farm size increases from 700 acres to 1500 acres, the total machinery related cost per acre goes down slightly. The machinery capacity for these two farm sizes differ greatly, however.

Chapter 7

Summary and Conclusions

7.1 Summary

The goal of this project was to adapt a machinery selection and scheduling program for Virginia agriculture. The Farm Machinery Selection Program developed by Dr. John C. Siemens for Illinois was chosen. Due to differences in soil type, weather conditions, and machinery availability between Virginia and Illinois, the original program cannot be applied to Virginia farms directly. Modifications were done to make it suitable for Virginia.

The original program was written in the C programming language and the source code has more than 15,000 lines. In the view of software engineering, the most difficult part of the entire software life cycle is software maintenance especially when there is no significant documentation. This is what occurred with this project. The program to be adapted to Virginia agriculture contained only executable files, user's manual, and non-commented source code. No other significant documentation existed.

In order to find out what parts of the program to modify and how to modify them, the program was fully studied and checked with many different situations. The structure of the program was finally understood. Methodologies employed by the program, such as the one used to calculate timeliness costs, were revealed.

After having carefully studied the program, it was found that this program is flexible enough to be adapted to the regions outside Illinois where the program was

originally developed. Methodologies employed to select an optimum machinery set for a specific farm are suitable for Virginia farming systems, and need not be changed based on the results of comparisons made. Regional and farm-related information are stored in several data files. It was found that these data files and some parts of the source code dealing with human-computer interface had to be modified to make the program easier to use and applicable to regions outside Illinois. Data file structures and relationships among them have been identified and properly modified according to the characteristics of Virginia farming systems. The modified version was run with a set data representing a hypothetical farm which is considered typical for Eastern Virginia. The results were discussed.

7.2 Conclusions

While the primary purpose of the program has been to determine the optimal machinery set for a farm, the program provides other benefits and applications. For example, the program can be used to determine the effects of changing farm size or crop on the suitability of presently owned machinery and available labor. Also the effect on machinery-related costs can be estimated for different crops, crop prices and yields, interest rate, machinery purchase prices, fuel prices, cost and availability of labor and other variables. It should be mentioned here that the methodologies used in the program have some limitations.

First, it is not easy to use the program to handle existing machinery. Although the program provides a run option (without optimization) to allow the program user to input existing machinery on the farm, the number of tractors is limited to six and the number of combines is limited to three. The program cannot be used if a farmer owns more than six tractors and/or more than three combines, and he wants to use this program to calculate the total machinery-related cost based on all existing machinery.

Second, the program can only deal with two tractor sizes and one combine size. This means the optimum machinery set selected by the program can have up to six tractors and three combines but the tractor sizes are limited to two and the combine size is limited to one. This may not be practical for Virginia agriculture because farms in Virginia usually have more than two tractor sizes and one combine size to have enough flexibility. If this program is used to deal with existing machinery using the “without optimization” run option, and the farm has more than two tractor sizes and /or one combine size, the user must make close substitutions to get the program to run. For example, if the farm has four tractors with sizes of 55, 65, 100, 110 horsepower respectively, the user must enter these four tractors as two tractors with size of 60, and two with size of 100 horsepower (available tractor sizes within this program are set to be 60, 80, 100, ...hp). Comparisons of farm schedules on a relative basis should still be close, however.

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APPENDIX A

Table A1: Implements Matched to Tractors with Corresponding Productivity Values

Machinery	Productivity Acres/Hour	Purchase Price, \$
60 HP TRACTOR	0.00	34600.00
2*16 MOLDBOARD PLOW	1.47	4050.00
6 FT. CHISEL PLOWM	1.14	5700.00
12 FT. DISK HARROW	2.73	5700.00
13 FT. FIELD CULT.	5.80	2890.00
6 FT. ROTARY CHOPPER	2.40	3600.00
4 ROW PLANTER	2.66	13100.00
4 ROW CULTIVATOR	3.88	3800.00
15 FT. ROTARY HOE	6.00	4100.00
7 KNIFE APPLICATOR	0.00	0.00
40 FT. FERTILIZER AP	20.00	0.00
40 FT. SPRAYER	0.00	3000.00
10 FT. DRILL	3.15	19200.00
10 FT ROTARY MOWER	0.00	2400.00
3PT SPREADER	0.00	3000.00
2-ROW FORAGE CHOPPER	0.00	0.00
COMBINATION TOOL	0.00	0.00
7 FT. MOWER	3.60	3600.00
7.5 FT. WHEEL RAKE	3.27	2100.00
7.25 FT. MOWER-COND.	2.81	10300.00
BALER (PTO) TWINE	2.71	10400.00
80 HP TRACTOR	0.00	39000.00
3*18 MOLDBOARD PLOW	1.97	6000.00
8 FT. CHISEL PLOW	1.50	7400.00
12 FT. DISK HARROW	3.09	5700.00
15 FT. FIELD CULT.	6.70	3000.00
10 FT ROTARY CHOPPER	4.50	6050.00
4 ROW PLANTER	2.66	13100.00
4 ROW CULTIVATOR	3.88	3800.00
21 FT. ROTARY HOE	8.67	5600.00
7 KNIFE APPLICATOR	8.18	0.00
40 FT. FERTILIZER AP	20.00	0.00
40 FT. SPRAYER	20.00	3000.00
10 FT. DRILL	3.50	19200.00
10 FT ROTARY MOWER	0.00	2400.00
3PT SPREADER	10.00	3000.00
2-ROW FORAGE CHOPPER	0.90	23000.00
12 FT. COMBIN. TOOL	5.00	9500.00
7 FT. MOWER	3.60	3600.00
9.25 FT. WHEEL RAKE	4.03	2500.00
7.25 FT. MOWER-COND.	3.16	10300.00
BALER (PTO) TWINE	2.71	10400.00

**Table A1: Implements Matched to Tractors with Corresponding Productivity Values
Cont'd**

Machinery	Productivity Acres/Hour	Purchase Price, \$
100 HP TRACTOR	0.00	56300.00
4*18 MOLDBOARD PLOW	2.47	9500.00
8 FT. CHISEL PLOW	1.70	7400.00
13 FT. DISK HARROW	3.52	7700.00
18 FT. FIELD CULT.	9.00	4900.00
14 FT FLAIL SHREDDER	5.60	7800.00
12 ROW PLANTER	7.57	35900.00
12 ROW CULTIVATOR	11.10	14000.00
21 FT. ROTARY HOE	8.80	5600.00
7 KNIFE APPLICATOR	8.18	0.00
40 FT. FERTILIZER AP	20.00	0.00
40 FT SPRAYER	20.00	3000.00
10 FT. DRILL	4.70	19200.00
10 FT ROTARY MOWER	0.00	2400.00
3PT SPREADER	10.00	3000.00
2-ROW FORAGE CHOPPER	1.00	23000.00
12 FT. COMBIN. TOOL	6.64	9500.00
7 FT. MOWER	3.60	3600.00
11 FT. WHEEL RAKE	4.80	2900.00
9.25 FT. MOWER-COND.	4.04	11800.00
BALER (PTO) TWINE	5.43	12700.00
#		
120 HP TRACTOR	0.00	65500.00
5*16 MOLDBOARD PLOW	2.97	10700.00
11 FT. CHISEL PLOW	2.60	9100.00
18 FT. DISK HARROW	4.91	13700.00
21 FT. FIELD CULT.	10.50	11500.00
14 FT FLAIL SHREDDER	6.30	7800.00
12 ROW PLANTER	7.57	35900.00
12 ROW CULTIVATOR	11.10	14000.00
21 FT. ROTARY HOE	8.80	5600.00
9 KNIFE APPLICATOR	10.22	0.00
40 FT. FERTILIZER AP	20.00	0.00
40 FT SPRAYER	20.00	3000.00
15 FT. DRILL	5.90	25400.00
10 FT ROTARY MOWER	3.00	2400.00
3 PT SPREADER	10.00	3000.00
3-ROW FORAGE CHOPPER	1.36	32000.00
15 FT. COMBIN. TOOL	8.17	11800.00
7 FT. MOWER	3.60	3600.00
11 FT. WHEEL RAKE	4.80	2900.00
12 FT. MOWER-COND.	4.04	21100.00
BALER (PTO) WIRE	5.43	13900.00

Table A1 Implements Matched to Tractors with Corresponding Productivity Values
Cont'd

Machinery	Productivity Acres/Hour	Purchase Price, \$
140 HP TRACTOR	0.00	70000.00
5*18 MOLDBOARD PLOW	3.48	10700.00
11 FT. CHISEL PLOW	2.75	9100.00
18 FT. DISK HARROW	6.00	15600.00
23 FT. FIELD CULT.	12.60	12000.00
14 FT FLAIL SHREDDER	7.00	7800.00
12 ROW PLANTER	7.57	35900.00
12 ROW CULTIVATOR	11.10	14000.00
28 FT. ROTARY HOE	11.73	12200.00
9 KNIFE APPLICATOR	10.22	0.00
40 FT. FERTILIZER AP	20.00	0.00
40 FT SPRAYER	20.00	3000.00
15 FT. DRILL	6.50	25400.00
10 FT ROTARY MOWER	4.00	2400.00
3 PT SPREADER	10.00	3000.00
3-ROW FORAGE CHOPPER	1.40	32000.00
15 FT. COMBIN. TOOL	9.00	11800.00
7 FT. MOVER	3.60	3600.00
11 FT. WHEEL RAKE	4.80	2900.00
12 FT. MOWER-COND.	4.04	21100.00
BALER (PTO) WIRE	5.43	13900.00
160 HP TRACTOR	0.00	75000.00
6*18 MOLDBOARD PLOW	3.94	11900.00
11 FT.CHISEL PLOW	3.12	9100.00
25 FT. DISK HARROW	6.79	17700.00
29 FT. FIELD CULT.	15.20	13300.00
20 FT FLAIL SHREDDER	8.50	12400.00
12 ROW PLANTER	7.57	35900.00
12 ROW CULTIVATOR	11.10	14000.00
28 FT. ROTARY HOE	11.73	12200.00
11 KNIFE APPLICATOR	12.27	0.00
40 FT. FERTILIZER AP	20.00	0.00
40 FT SPRAYER	20.00	3000.00
15 FT. DRILL	7.10	25400.00
10 FT ROTARY MOWER	4.00	2400.00
3 PT SPREADER	10.00	3000.00
3-ROW FORAGE CHOPPER	1.60	32000.00
19 FT. COMBIN. TOOL	11.40	16000.00
7 FT. MOWER	3.60	3600.00
11 FT. WHEEL RAKE	4.80	2900.00
14 FT. MOWER-COND.	4.04	21700.00
BALER (PTO) WIRE	5.43	13900.00

Table A1 Implements Matched to Tractors with Corresponding Productivity Values
Cont'd

Machinery	Productivity Acres/Hour	Purchase Price, \$
180 HP TRACTOR	0.00	81000.00
7*18 MOLDBOARD PLOW	4.45	15900.00
13 FT. CHISEL PLOW	3.22	11400.00
28 FT. DISK HARROW	7.64	21700.00
33 FT. FIELD CULT.	18.10	15200.00
20 FT FLAIL SHREDDER	9.00	12400.00
12 ROW PLANTER	7.57	35900.00
12 ROW CULTIVATOR	11.10	14000.00
41 FT. ROTARY HOE	17.33	15000.00
11 KNIFE APPLICATOR	12.27	0.00
40 FT. FERTILIZER AP	20.00	0.00
40 FT SPRAYER	20.00	3000.00
15 FT. DRILL	7.10	25400.00
10 FT ROTARY MOWER	4.00	2400.00
3 PT SPREADER	10.00	3000.00
4-ROW FORAGE CHOPPER	1.82	42600.00
19 FT. COMBIN. TOOL	11.40	16000.00
7 FT. MOWER	3.60	3600.00
11 FT. WHEEL RAKE	4.80	2900.00
14 FT. MOWER-COND.	4.04	21700.00
BALER (PTO) WIRE	5.43	13900.00
200 HP TRACTOR	0.00	88200.00
7*18 MOLDBOARD PLOW	4.94	15900.00
13 FT. CHISEL PLOW	3.36	11400.00
32 FT. DISK HARROW	8.73	22600.00
36 FT. FIELD CULT.	19.80	15800.00
20 FT FLAIL SHREDDER	9.50	12400.00
12 ROW PLANTER	7.57	35900.00
12 ROW CULTIVATOR	11.10	14000.00
41 FT. ROTARY HOE	17.33	15000.00
11 KNIFE APPLICATOR	12.27	0.00
40 FT. FERTILIZER AP	20.00	0.00
40 FT SPRAYER	20.00	3000.00
15 FT. DRILL	7.10	25400.00
10 FT ROTARY MOWER	4.00	2400.00
3 PT SPREADER	10.00	3000.00
4-ROW FORAGE CHOPPER	2.18	42600.00
30 FT. COMBIN. TOOL	18.00	19200.00
7 FT. MOWER	3.60	3600.00
11 FT. WHEEL RAKE	4.80	2900.00
16 FT. MOWER-COND.	4.04	22600.00
BALER (PTO) WIRE	5.43	13900.00

Table A1 Implements Matched to Tractors with Corresponding Productivity Values
Cont'd

Machinery	Productivity Acres/Hour	Purchase Price, \$
240 HP TRACTOR	0.00	106200.00
8*18 MOLDBOARD PLOW	5.45	17200.00
16 FT. CHISEL PLOW	4.16	12800.00
32 FT. DISK HARROW	9.20	22600.00
42 FT. FIELD CULT.	25.20	16600.00
20 FT FLAIL SHREDDER	10.00	12400.00
12 ROW PLANTER	7.57	35900.00
12 ROW CULTIVATOR	11.10	14000.00
41 FT. ROTARY HOE	17.33	15000.00
11 KNIFE APPLICATOR	12.27	0.00
40 FT. FERTILIZER AP	20.00	0.00
40 FT SPRAYER	20.00	3000.00
15 FT. DRILL	7.10	25400.00
10 FT ROTARY MOWER	4.00	2400.00
3 PT SPREADER	10.00	3000.00
4-RROW FORAGE CHOPPER	2.18	42600.00
30 FT. COMBIN. TOOL	18.00	25300.00
7 FT. MOWER	3.60	3600.00
11 FT. WHEEL RAKE	4.80	2900.00
16 FT. MOWER-COND.	4.04	22600.00
BALER (PTO) WIRE	5.43	13900.00

Table A2 Attachments Matched to Combines with Corresponding Productivity Values and Assumed Purchase Prices

Machinery	Productivity Acres/Hour	Purchase Price, \$
140 HP COMBINE	0.00	82000.00
4 ROW CORN HEAD	1.00	15900.00
18 FT GRAIN PLATFORM	2.40	13300.00
180 HP COMBINE	0.00	101900.00
6 ROW CORN HEAD	1.50	21500.00
20 FT GRAIN PLATFORM	2.90	14100.00
215 HP COMBINE	0.00	117800.00
8 ROW CORN HEAD	1.99	28000.00
22 FT GRAIN PLATFORM	3.12	14800.00
260 HP COMBINE	0.00	133000.00
12 ROW CORN HEAD	3.50	43800.00
24 FT GRAIN PLATFORM	3.87	15800.00

Table A3 Planter and Row Cultivator with Productivity Values and Assumed Purchase Prices

Machinery	Productivity Acres/Hour	Purchase Price, \$
4 ROW PLANTER	2.66	13100.00
4 ROW CULTIVATOR	3.88	3800.00
6 ROW PLANTER	4.00	17920.00
6 ROW CULTIVATOR	5.82	4500.00
8 ROW PLANTER	5.74	22700.00
8 ROW CULTIVATOR	7.76	7100.00
12 ROW PLANTER	7.57	35900.00
12 ROW CULTIVATOR	11.10	14000.00
16 ROW PLANTER	9.60	58400.00
16 ROW CULTIVATOR	14.00	13500.00
24 ROW PLANTER	13.66	75000.00
12 ROW CULTIVATOR	11.10	14000.00

Stored array used to match size of tractors, combine corn heads and planters:

0	-1	-1	-1	-1	-1	-1	-1
0	1	2	-1	2	-1	-1	-1
0	1	2	3	2	3	4	-1
0	1	2	3	2	3	4	5
0	1	2	3	2	3	4	5
0	1	2	3	2	3	4	5
0	1	2	3	2	3	4	5
0	1	2	3	2	3	4	5

Table A4 Values of Repair Cost Constants RV1, RV2, RC1 RC2 and Life of Each Machine.

Machine	RV1	RV2	RC1	RC2	LIFE
TRACTOR	0.60	0.935	0.007	2.00	12000
MOLDBOARD PLOW	0.56	0.900	0.290	1.80	2000
CHISEL PLOW	0.56	0.900	0.280	1.40	2000
DISK STALKS	0.56	0.900	0.180	1.70	2000
FIELD CULTIVATE	0.56	0.900	0.270	1.40	2000
CHOP STALKS	0.56	0.900	0.280	1.40	1200
PLANT	0.56	0.900	0.320	2.10	1500
ROW CULTIVATE	0.56	0.900	0.170	2.20	2000
ROTARY HOE	0.56	0.900	0.230	1.40	2000
APPLY ANHYDROUS	0.56	0.900	0.630	1.30	1200
APPLY FERTILIZER	0.56	0.900	0.630	1.30	1200
SPRAY PESTICIDE	0.56	0.900	0.410	1.30	1500
DRILL	0.56	0.900	0.320	2.10	1500
ROTARY MOWER STALKS	0.56	0.900	0.280	1.40	2000
SPREADER SEED	0.56	0.900	0.280	1.40	2000
CHOP FORAGE	0.56	0.900	0.040	2.10	3000
COMBINATION TOOL	0.56	0.900	0.270	1.40	2000
MOW HAY	0.56	0.900	0.460	1.70	2000
RAKE HAY	0.56	0.900	0.170	1.40	2500
MOW & CONDITION	0.56	0.900	0.180	1.60	2500
BALE HAY	0.56	0.900	0.230	1.80	2000
SP COMBINE	0.67	0.920	0.040	2.10	3000
CORN HEAD	0.56	0.900	0.040	2.10	3000
GRAIN PLATFORM	0.64	0.900	0.040	2.10	3000

Table A5 Calendar Days Favorable for Field Work by Selected Period and Selected Regions of Illinois

Total Calendar Days	Average Number of Favorable Days			Number of Favorable Day Available 5 out 6 years		
	-----	-----	-----	-----	-----	-----
March 27- April 0914	4.1	5.9	3.0	1.7	2.0	1.0
April 10 - April 2314	7.9	6.9	6.4	5.0	3.6	2.4
April 24 - May 714	9.2	7.9	7.8	6.2	5.1	4.2
May 8 - May 2214	8.6	7.5	8.0	5.4	3.9	4.2
May 23 - June 414	10.2	9.1	9.4	8.2	6.5	6.0
June 05 - June 1814	9.7	9.5	6.5	6.4	6.4	7.0
June 19 - July 2 14	10.8	10.0	10.8	8.6	7.1	8.0
Aug. 30 - Sept. 1214	11.9	11.3	12.1	9.3	9.8	9.5
Sept. 13 - Sept 2614	10.2	9.6	10.8	6.6	7.2	8.2
Sept 27 - Oct. 1014	10.7	9.4	10.3	6.7	7.9	7.6
Oct. 11 - Oct. 2414	11.5	10.8	10.6	8.8	10.0	8.1
Oct. 25 - Nov. 714	10.4	10.5	10.6	6.4	7.2	7.6
Nov. 8 - Nov. 2114	10.3	10.0	8.6	7.9	8.1	7.6
Nov. 22 - Dec. 614	6.5	7.5	4.8	5.9	3.7	1.6

Table A6 Listing of Probability File “prob2.jtk”

January								
From 01 - 08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 09 - 16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 17 - 24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 25 - 28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
February								
From 01 - 08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 09 - 16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 17 - 24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 25 - 31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
March								
From 01 - 08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 09 - 16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 17 - 24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 25 - 31	0.00	0.00	0.07	0.07	0.07	0.07	0.07	
April								
From 01 - 08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
From 09 - 16	0.07	0.17	0.17	0.17	0.17	0.17	0.17	0.17
From 17 - 24	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.30
From 25 - 31	0.30	0.30	0.30	0.30	0.30	0.30	0.00	
May								
From 01 - 08	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
From 09 - 16	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
From 17 - 24	0.30	0.30	0.30	0.30	0.30	.030	0.43	0.43
From 25 - 31	0.43	0.43	0.43	0.43	0.43	0.43	0.43	
June								
From 01 - 08	0.43	0.43	0.43	0.43	0.50	0.50	0.50	0.50
From 09 - 16	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
From 17 - 24	0.50	0.50	0.57	0.57	0.57	0.57	0.57	0.57
From 25 - 31	0.57	0.57	0.57	0.57	0.57	0.57	0.00	
July								
From 01 - 08	0.57	0.57	0.62	0.62	0.62	0.62	0.62	0.62
From 09 - 16	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
From 17 - 24	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
From 25 - 31	0.62	0.62	0.62	0.62	0.62	0.62	0.62	
August								
From 01 - 08	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
From 09 - 16	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
From 17 - 24	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
From 25 - 31	0.62	0.62	0.62	0.62	0.68	0.68	0.68	

Table A6 Listing of Probability File “prob2.jtk” (Cont’d)

September								
From 01 - 08	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
From 09 - 16	0.68	0.68	0.68	0.59	0.59	0.59	0.59	0.59
From 17 - 24	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59
From 25 - 31	0.59	0.54	0.54	0.54	0.54	0.54	0.54	0.00
October								
From 01 - 08	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
From 09 - 16	0.54	0.58	0.58	0.58	0.58	0.58	0.58	0.58
From 17 - 24	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.54
From 25 - 31	0.59	0.54	0.54	0.54	0.54	0.54	0.54	
November								
From 01 - 08	0.54	0.54	0.54	0.54	0.54	0.54	<u>0.40</u>	<u>0.40</u>
From 09 - 16	<u>0.40</u>	<u>0.40</u>	<u>0.40</u>	<u>0.40</u>	<u>0.40</u>	<u>0.40</u>	<u>0.40</u>	<u>0.40</u>
From 17 - 24	<u>0.40</u>	<u>0.40</u>	<u>0.40</u>	<u>0.40</u>	0.11	0.11	0.11	0.11
From 25 - 31	0.11	0.11	0.11	0.11	0.11	0.11	0.00	
December								
From 01 - 08	0.11	0.11	0.11	0.11	0.11	0.00	0.00	0.00
From 09 - 16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 17 - 24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 25 - 31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

Table A7 Number of Days Suitable for Fieldwork, Selected Dates 1986 — 1992

Period Comparable to Week Ending	1986	1987	1988	1989	1990	1991	1992	7- year avg.
March 29 — April 4	5.5	4.8	5.4	3.2	2.0	3.5	3.8	4.0
April 5 — 11	6.3	2.9	3.6	2.0	2.6	5.5	5.5	4.1
April 12 — 18	5.2	3.3	3.9	3.3	4.1	4.0	5.5	4.2
April 19 — 25	4.3	1.6	3.8	4.3	5.8	6.0	3.5	4.2
April 26 — May 2	5.1	1.8	5.3	5.0	4.0	5.0	3.8	4.3
May 3 — 9	5.8	3.0	3.8	1.7	4.0	5.0	3.3	4.6
May 10 — 16	5.7	3.9	4.2	0.6	5.0	5.5	4.5	4.2
May 17 — 23	4.1	4.7	3.1	3.0	3.2	4.5	3.3	3.7
May 24 — 30	3.0	4.3	3.3	5.2	2.0	6.0	3.0	3.8
May 31 — June 6	4.3	4.9	5.1	6.3	5.0	5.5	3.0	4.9
June 7 — 13	5.6	3.3	5.3	2.3	6.0	6.0	2.5	4.4
June 14 — 20	5.6	5.4	6.1	2.7	5.5	4.0	4.5	4.8
June 21 — 27	6.0	5.6	6.1	1.5	6.4	4.5	4.5	4.9
June 28 — July 4	6.0	5.6	6.1	4.3	6.0	5.5	5.5	5.6
July 5 — 11	4.5	5.6	6.3	3.4	5.4	5.5	5.5	5.2
July 12 — 18	6.0	4.8	5.6	4.7	4.2	6.1	6.0	5.3
July 19 — 25	5.9	5.4	4.4	3.7	6.2	6.0	4.5	5.2
July 26 — Aug. 1	4.6	6.3	3.3	6.5	6.2	3.5	4.0	4.9
Aug. 2 — 8	5.1	6.0	6.0	4.5	4.8	4.8	5.0	5.2
Aug. 9 — 15	4.0	6.2	6.1	4.8	5.0	4.5	4.0	4.9
Aug. 16 — 22	3.9	6.3	6.4	3.7	3.5	5.0	3.0	4.5
Aug. 23 — 29	1.7	6.1	5.8	2.5	5.1	6.0	5.0	4.6
Aug. 30 — Sept. 5	3.4	6.2	4.7	5.2	6.1	6.0	5.0	5.2
Sept. 6 — 12	2.4	6.1	5.4	5.3	5.3	6.0	3.7	4.9
Sept. 13 — 19	4.1	2.5	6.2	4.5	5.4	6.1	6.0	5.0
Sept. 20 — 26	4.4	4.4	5.9	2.3	6.1	5.0	5.4	4.9
Sept. 27 — Oct. 3	6.2	4.7	5.7	3.4	6.1	5.5	4.4	5.4
Oct. 4 — 10	6.3	5.3	5.0	4.1	5.0	6.0	4.5	5.2
Oct. 11 — 17	6.1	4.8	6.4	6.1	4.5	5.0	5.2	5.4
Oct. 18 — 24	4.9	5.8	5.7	2.3	2.3	5.8	6.0	4.7
Oct. 25 — 31	6.0	6.0	5.4	6.1	5.5	6.4	6.3	6.0
Nov. 1 — 7	5.2	5.1	4.4	5.2	6.0	6.5	2.0	4.5
Nov 8 — 14	3.3	6.5	5.5	3.3	5.5	4.5	4.0	4.7
Nov. 15 — 21	2.5	2.9	4.3	3.6	6.0	5.8	5.0	4.3
Nov. 22 — 28	2.6	4.1	4.1	4.0	5.5	5.5	2.0	4.0
Nov. 29 — Dec. 4	1.9	5.1	3.5	3.9	4.1	2.5	3.0	3.4

Table A8 Data Derived from Table A7, Used to Created Work-Day Probability Files

Table Period Comparable to Week Ending	7-year Average	6 out of 7 years	5 out of 7 years	4 out of 7 years	3 out of 7 years
March 29 — April 4	4.0	3.2	3.5	3.8	4.8
April 5 — 11	4.1	2.6	2.9	3.6	5.5
April 12 — 18	4.2	3.9	4.0	4.1	5.2
April 19 — 25	4.2	3.5	3.8	4.3	5.8
April 26 — May 2	4.3	3.8	4.0	5.0	5.1
May 3 — 9	4.6	3.0	3.2	3.8	4.0
May 10 — 16	4.2	3.9	4.2	4.5	5.0
May 17 — 23	3.7	3.1	3.2	3.3	4.1
May 24 — 30	3.8	3.0	3.3	4.3	5.2
May 31 — June 6	4.9	4.3	4.9	5.0	5.1
June 7 — 13	4.4	2.5	3.3	5.3	5.6
June 14 — 20	4.8	4.0	4.5	5.4	5.5
June 21 — 27	4.9	4.5	4.5	5.6	6.0
June 28 — July 4	5.6	5.5	5.5	5.6	6.0
July 5 — 11	5.2	4.5	5.4	5.5	5.5
July 12 — 18	5.3	4.7	4.8	5.6	6.0
July 19 — 25	5.2	4.4	4.5	5.4	5.9
July 26 — Aug. 1	4.9	3.5	4.0	4.6	6.2
Aug. 2 — 8	5.2	4.8	4.8	5.0	5.1
Aug. 9 — 15	4.9	4.0	4.5	4.8	5.0
Aug. 16 — 22	4.5	3.5	3.7	3.9	5.0
Aug. 23 — 29	4.6	2.5	5.0	5.1	5.8
Aug. 30 — Sept. 5	5.2	4.7	5.0	5.2	6.0
Sept. 6 — 12	4.9	3.7	5.3	5.3	5.4
Sept. 13 — 19	5.0	4.1	4.5	5.4	6.0
Sept. 20 — 26	4.9	4.4	4.4	5.0	5.4
Sept. 27 — Oct. 3	5.4	4.4	4.7	5.5	5.7
Oct. 4 — 10	5.2	4.5	5.0	5.0	5.3
Oct. 11 — 17	5.4	4.8	5.0	5.2	6.1
Oct. 18 — 24	4.7	2.3	4.9	5.7	5.8
Oct. 25 — 31	6.0	5.5	6.0	6.0	6.1
Nov. 1 — 7	4.5	4.4	5.1	5.2	5.2
Nov 8 — 14	4.7	3.3	4.0	4.5	5.5
Nov. 15 — 21	4.3	2.9	3.6	4.3	5.0
Nov. 22 — 28	4.0	2.6	4.0	4.1	4.1
Nov. 29 — Dec. 4	3.4	2.5	3.0	3.5	3.9

Table A9 Listing of File prob50.jtk

January								
From 01 - 08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 09 - 16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 17 - 24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 25 - 28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
February								
From 01 - 08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 09 - 16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 17 - 24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 25 - 31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
March								
From 01 - 08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 09 - 16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 17 - 24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 25 - 31	0.00	0.00	0.00	0.00	0.57	0.57	0.57	
April								
From 01 - 08	0.57	0.57	0.57	0.57	.059	.059	0.59	0.59
From 09 - 16	0.59	0.59	0.59	0.60	0.60	0.60	0.60	0.60
From 17 - 24	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
From 25 - 31	0.60	0.61	0.61	0.61	0.61	0.61	0.61	
May								
From 01 - 08	0.61	0.66	0.66	0.66	0.66	0.66	0.66	0.66
From 09 - 16	0.66	0.60	0.60	0.60	0.60	0.60	0.60	0.60
From 17 - 24	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.54
From 25 - 31	0.54	0.54	0.54	0.54	0.54	0.54	0.70	
June								
From 01 - 08	0.70	0.70	0.70	0.70	0.70	0.70	0.63	0.63
From 09 - 16	0.63	0.63	0.63	0.63	0.63	0.69	0.69	0.69
From 17 - 24	0.69	0.69	0.69	0.69	0.70	0.70	0.70	0.70
From 25 - 31	0.70	0.70	0.70	0.63	0.63	0.63	0.00	
July								
From 01 - 08	0.63	0.63	0.63	0.63	0.74	0.74	0.74	0.74
From 09 - 16	0.74	0.74	0.74	0.76	0.76	0.76	0.76	0.76
From 17 - 24	0.76	0.76	0.74	0.74	0.74	0.74	0.74	0.74
From 25 - 31	0.74	0.70	0.70	0.70	0.70	0.70	0.70	
August								
From 01 - 08	0.70	0.74	0.74	0.74	0.74	0.74	0.74	0.74
From 09 - 16	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.64
From 17 - 24	0.64	0.64	0.64	0.64	0.64	0.64	0.66	0.66
From 25 - 31	0.66	0.66	0.66	0.66	0.66	0.74	0.74	

Table A9 Listing of File prob50.jtk (cont'd)

September								
From 01 - 08	0.74	0.74	0.74	0.74	0.74	0.70	0.70	0.70
From 09 - 16	0.70	0.70	0.70	0.70	0.71	0.71	0.71	0.71
From 17 - 24	0.71	0.71	0.71	0.70	0.70	0.70	0.70	0.70
From 25 - 31	0.70	0.70	0.77	0.77	0.77	0.77	0.00	
October								
From 01 - 08	0.77	0.77	0.77	0.74	0.74	0.74	0.74	0.74
From 09 - 16	0.74	0.74	0.77	0.77	0.77	0.77	0.77	0.77
From 17 - 24	0.77	0.67	0.67	0.67	0.67	0.67	0.67	0.67
From 25 - 31	0.86	0.86	0.86	0.86	0.86	0.86	0.86	
November								
From 01 - 08	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.67
From 09 - 16	0.67	0.67	0.67	0.67	0.67	0.67	0.61	0.61
From 17 - 24	0.61	0.61	0.61	0.61	0.61	0.57	0.57	0.57
From 25 - 31	0.57	0.57	0.57	0.57	0.49	0.49	0.49	
December								
From 01 - 08	0.49	0.49	0.49	0.49	0.00	0.00	0.00	0.00
From 09 - 16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 17 - 24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
From 25 - 31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

Table A10 Contents of the Original File LISTOPER.JTK

#OPERATION LIST				
no operation	0	0	0	0
COMBINE CORN	1	2	1	3
COMBINE SOYBEANS	2	2	2	1
COMBINE WHEAT	3	2	2	2
COMBINE OAT	4	2	2	3
COMBINE SORGHUM	5	2	2	1
MOLDBOARD PLOW	6	1	1	5
CHISEL PLOW	7	1	2	5
DISK HARROW	8	1	3	5
FIELD CULTIVATE	9	1	4	5
SUBSOILER	10	1	13	5
PARAPLOW	11	1	14	5
CHOP FORAGE	12	1	15	5
CHOP STALKS	13	1	5	4
APPLY ANHYDROUS	15	1	9	1
APPLY FERTILIZER	16	1	10	1
SPRAY PESTICIDE	17	1	11	1
ROW CULTIVATE	18	1	7	5
ROTARY HOE	19	1	8	1
COMBINATION TOOL	20	1	16	4
PLANT CORN	21	1	6	2
PLANT SOYBEANS	22	1	6	3
DRILL WHEAT	23	1	12	4
DRILL OAT	24	1	12	1
DRILL SOYBEANS	25	1	12	3
PLANT SORGHUM	26	1	6	1
MOW HAY	27	1	17	6
RAKE HAY	28	1	18	6
MOW & CONDITION	29	1	19	6
BALE HAY	30	1	20	6

Table A11 List of Modified “listoper.jtk”

#OPERATION LIST				
no operation	0	0	0	0
COMBINE CORN	1	2	1	3
COMBINE SOYBEANS/FS	2	2	2	1
COMBINE WHEAT	3	2	2	2
COMBINE SOYBEANS/DC	4	2	2	1
COMBINE OATS	5	2	2	3
MOLDBOARD PLOW	6	1	1	5
CHISEL PLOW	7	1	2	5
DISK HARROW	8	1	3	5
FIELD CULTIVATE	9	1	4	5
ROTARY MOWER STALKS	10	1	13	5
SPREADER SEED	11	1	14	5
CHOP FORAGE	12	1	15	5
CHOP STALKS	13	1	5	4
DISK STALKS	14	1	3	4
APPLY ANHYDROUS	15	1	9	1
APPLY FERTILIZER	16	1	10	1
SPRAY PESTICIDE	17	1	11	1
ROW CULTIVATE	18	1	7	5
ROTARY HOE	19	1	8	1
COMBINATION TOOL	20	1	16	4
PLANT CORN	21	1	6	2
PLANT SOYBEANS/FS	22	1	6	3
DRILL WHEAT	23	1	12	4
PLANT SOYBEANS/DC	24	1	6	3
DRILL OATS	25	1	12	1
DRILL SOYBEANS	26	1	12	3
MOW HAY	27	1	17	6
RAKE HAY	28	1	18	6
MOW & CONDITION	29	1	19	6
BALE HAY	30	1	20	6

Table A12 Contents of the File CFACTORS.JTK

#COST FACTORS					
TRACTOR	0.60	0.935	0.007	2.00	12000
MOLDBOARD	0.56	0.900	0.290	1.80	2000
CHISEL PLOW	0.56	0.900	0.280	1.40	2000
DISK STALKS	0.56	0.900	0.180	1.70	2000
FIELD CULTIVATE	0.56	0.900	2.700	1.40	2000
CHIOP STALKS	0.56	0.900	0.280	1.40	1200
PLANT CORN	0.56	0.900	0.320	2.10	1500
ROW CULTIVATE	0.56	0.900	0.170	2.20	2000
ROTARY HOE	0.56	0.900	0.230	1.40	2000
APPLY FERTILIZER	0.56	0.900	0.630	1.30	12000
APPLY ANHYDROUS	0.56	0.900	0.630	1.30	12000
SPRAY PESTICIDE	0.56	0.900	0.410	1.30	1500
DRILL	0.56	0.900	0.320	2.10	1500
SUBSOILER	0.56	0.900	0.280	1.40	2000
PARAPLOW	0.56	0.900	0.280	1.40	2000
CHOP FORAGE	0.56	0.900	0.040	2.10	3000
COMBINATION TOOL	0.56	0.900	0.270	1.40	2000
MOW HAY	0.56	0.900	0.460	1.70	2000
RAKE HAY	0.56	0.900	0.170	1.40	2500
MOW & CONDITION	0.56	0.900	0.180	1.60	2500
BALE HAY	0.56	0.900	0.230	1.80	2000
SP COMBINE	0.67	0.920	0.040	2.10	3000
CORN HEAD	0.56	0.900	0.040	2.10	3000
GRAIN PLATFORM	0.64	0.900	0.040	2.10	3000

Table A13 Contents of the File HARVPROD.JTK

#HARVEST PRODUCTIVITY		
140 HP COMBINE	0.00	82000.00
4 ROW CORN HEAD	2.74	15900.00
18 FT GRAIN PLATFORM	4.59	13300.00
#		
180 HP COMBINE	0.00	101900.00
6 ROW CORN HEAD	4.14	21500.00
20 FT GRAIN PLATFORM	5.50	14100.00
#		
215 HP COMBINE	0.00	117800.00
8 ROW CORN HEAD	5.51	28000.00
22 FT GRAIN PLATFORM	6.07	14800.00
#		
260 HP COMBINE	0.00	133000.00
12 ROW CORN HEAD	8.27	43800.00
24 FT GRAIN PLATFORM	7.40	15800.00
#		

Appendix B

Detailed Outputs for The Hypothetical Farm

Program Inputs:

Data inputs for the hypothetical farm include data for tractors and combines, match implements to tractors, economics and timeliness, and required field operations. These inputs are listed in the tables from B1 to B4.

Table B1 Entry Screen For Tractor And Combine Data

Input Data for Farm

<END = Exit>

Enter Data for TRACTORS and COMBINES					
	Quantity	Size*		Quantity	Size*
Tractors:			Combines:	1 (Max = 3)	4
Large	1	3	Corn Heads:	1 (Max = 3)	
Small	1	3	Grain Platforms:	1 (Max = 3)	
Total (Max = 6)					
* Needed To Run Without Optimization.					
Available Tractor Sizes:			Available Combine Sizes:		
0 = 60 HP	5 = 160 HP		0 = 140 HP	(4 Row Head)	
1 = 80 HP	6 = 180 HP		1 = 180 HP	(6 Row Head)	
2 = 100 HP	7 = 200 HP		2 = 215 HP	(8 Row Head)	
3 = 120 HP	8 = 240 HP		3 = 260 HP	(12 Row Head)	
4 = 140 HP					

Table B2 Matching Implements to Tractors

Input Data for Farm

<END = Exit>

Match IMPLEMENTS to TRACTORS						
Planter Size : S (T or S)			Large Tractors: (L):			1
(T): Twice the combine size			Small Tractors: (S):			0
(S): Same as Combine Size			Total:			1
Implement	L	S	Implement	L	S	
Moldboard Plow	0	0	Spray Pesticide	0	1	
Chisel Plow	1	0	Drill	0	1	
Disk	1	0	Rotary Mower Stalks	1	0	
Field Cultivate	0	0	Spreader Seed	0	1	
Chop Stalks	0	0	Chop Forage	0	0	
Plant	1	0	Combination Tool	0	0	
Row Cultivate	0	0	Mow Hay	0	0	
Rotary Hoe	0	0	Rake Hay	0	0	
Apply Anhydrous	0	0	Mow & Condition	0	0	
Apply Fertilizer	1	0	Bale Hay	0	0	

Table B3 Entry Screen for Economic and Timeliness Inputs

Input Data for Farm

<END = Exit>

Enter ECONOMIC and TIMELINESS Date				
Operators:				
Number:	3	Cost (\$/hr):	5.25	
Economic Factors:				
Purchase Price, % of List:			90.0	
Housing, Interest, and Insurance:			10.0	
Percent Inflation:			3.0	
Fuel Price (\$/Gal):			\$ 0.7	
Timeliness Factors:			Penalty Dates	
	Prices	Yields	Planting	Harvesting
	(\$/Bu)		(Bu/A)	(Mo/Day)
(Mo/Day)				
Corn	2.60	120.0	4 / 15	9 / 20
Soybeans/FS	6.00	35.0	5 / 30	11 / 15
Wheat	2.85	60.0	11 / 5	7 / 1
Oats	6.00	40.0	5 / 31	10 / 15
Soybeans/DC	6.00	28.0	7 / 1	11 / 15

Table B4 Operation Entry Screen for the Hypothetical Farm

Input Data for Farm

< F1 = Help >

Enter Data For FIELD OPERATIONS						
Tillable Acres:		700.00				
Code No.	Field Operations	Earliest Start Date (Mo / Day)	Latest Finish date (Mo / Day)	Acres	Labor Availability (Hrs /Day)	Land Area
1	Combine Corn	9 1	0 0	400.0	10.0	0
10	Rotary Mower Stalks	9 2	0 0	400.0	10.0	0
8	Disk Harrow	9 3	0 0	400.0	10.0	0
11	Spreader Seed	9 4	0 0	400.0	10.0	0
8	Disk Seed In	9 5	0 0	400.0	10.0	0
2	Combine Soybean/FS	10 25	0 0	300.0	10.0	1
2	Combine Soybean/DC	10 25	0 0	300.0	10.0	2
8	Disk Harrow	10 25	0 0	300.0	10.0	2
23	Drill Wheat	10 25	0 0	300.0	10.0	2
16	Apply Fertilizer	11 10	0 0	300.0	10.0	2
16	Apply Fertilizer	3 27	0 0	400.0	10.0	0
17	Spray Pesticide	3 28	0 0	400.0	10.0	0
21	Plant Corn	3 30	0 0	400.0	10.0	0
8	Disk Harrow	4 27	0 0	300.0	10.0	1
16	Apply Fertilizer	4 29	0 0	300.0	10.0	1
7	Chisel Plow	4 30	0 0	300.0	10.0	1
8	Disk Harrow	5 14	0 0	300.0	10.0	1
22	Plant Soybeans / FS	5 15	0 0	300.0	10.0	1
3	Combine Wheat	6 15	0 0	300.0	10.0	2
26	Plant Soybeans / DC	6 15	0 0	300.0	10.0	2
17	Spray Pesticide	6 25	0 0	300.0	10.0	1
17	Spray Pesticide	7 1	0 0	300.0	10.0	2
17	Spray Pesticide	7 5	0 0	300.0	10.0	1
17	Spray Pesticide	8 15	0 0	300.0	10.0	2
0	no operation	0 0	0 0	0.0	0.0	0

Table B5 Machinery Price, and Annual Use

Machine Name	Purchase Price	-----Annual Hours	Use----- Acres
260 HP Combine	11970	347	
120 HP Tractor	58950	632	
120 HP Tractor	58950	316	
12 Row Corn Head	39420	114	400
24 FT Grain Platform	14220	233	900
11 FT Chisel Plow	8190	115	300
18 FT Disk Harrow	12330	346	1700
6 Row Planter	32310	132	1000
40 FT Fertilizer Application	0	50	1000
40 FT Sprayer	2700	80	1600
15 FT Drill	22860	51	300
10 FT Mower	2160	133	400
3 PT Spreader	2700	40	400

]Number of Operators = 4

Operator 1	would work	747.57	hours
Operator 2	would work	524.51	hours
Operator 1	would work	232.96	hours
Operator 1	would work	136.55	hours

Table B6 Estimated Cost for Each Field Operation in Dollars Per Acre

Machine Name	Years of Use	Annual Hours	Power and Machine Cost	Machine Cost only
260 HP Combine	5	314		
12 Row Corn Head	10	114	34.17	12.34
24 FT Grain Platform	7	233	22.35	2.61
120 HP Tractor	10	632		
120 HP Tractor	10	316		
11 FT Chisel Plow	9	115	12.6	4.5
18 FT Disk Harrow	5	346	6.36	2.07
6 Row Planter	6	132	9.25	6.46
40 FT Fertilizer Application	10	50	1.05	0
40 FT Sprayer	10	80	1.31	0.26
15 FT Drill	10	51	13.32	9.76
10 FT Mower	8	133	7.99	0.98
3 PT Spreader	10	40	2.97	0.86

Table B7: Average Annual Machinery Related Costs

Cost	\$ / Year	\$ / Acre
Machinery Fixed Cost	52377.51	52.38
Fuel Cost	7223.10	7.22
Repair Cost	9554.99	9.55
Total Machinery Cost	69155.62	69.16
Labor Cost	8618.33	8.62
Timeliness Cost	4378.29	4.38
Total Cost	82152.23	82.15

Table B8: Detailed Costs for the 260 HP COMBINE

List Price = \$133000.00				Purchase Price = 119700.00		
Fuel Price = \$ 0.70 / Gallon				Fuel Use = 13.16 Gallons / Hr		
Machine Use = 346.84 Hours / Yr						
Year	Total Hours	Percent of Life	Depreciation	HII *	Total Repair	Cost Per Hour
1	347	12	37719	11970	576	154.13
2	694	23	44277	19348	2525	104.57
3	1041	35	50311	26136	5939	88.39
4	1387	46	55862	32381	10881	80.66
5	1734	58	60969	38127	17395	76.38

Table B9: Detailed Costs for the 12 Row CORN HEAD

List Price = \$21500.00				Purchase Price = 19350.00		
Machinery Coverage = 400.0 Acres / Yr				Fuel Cost = \$2.63 / Acre		
Productivity = 3.5 Acres / Hr						
Annual Use = 114.3 Hours / Yr						
Year	Total Hours	Percent of Life	Depreciation	HII *	Total Repair	Cost Per Hour
1	114	4	17345	3942	18	53.26
2	229	8	19552	5929	81	31.95
3	343	11	21539	7717	190	24.54
4	457	15	23327	9326	348	20.63
5	571	19	24936	10774	557	18.13
6	686	23	26385	12078	817	16.37
7	800	27	27688	13251	1129	15.02
8	914	30	28862	14307	1494	13.96
9	1029	34	29917	15257	1914	13.08
10	1143	38	30868	16113	2388	12.34
Costs for 260 HP Combine			Plus	12 Row CORN HEAD	Total	
\$ / ACRE = 76.38/3.5			+	12.34	34.17	

Table B10: Detailed Costs for the 24 FT GRAIN PLATFORM

List Price = \$15800.00				Purchase Price = 14220.00		
Machinery Coverage = 900.0 Acres / Yr				Fuel Cost = \$ 2.38 / Acre		
Productivity = 3.84 Acres / Hr						
Annual Use = 232.6 Hours / Yr						
Year	Total Hours	Percent of Life	Depreciation	HII *	Total Repair	Cost Per Hour
1	233	8	5119	1422	30	7.30
2	465	16	6029	2241	130	4.67
3	698	23	6848	2978	305	3.75
4	930	31	7586	3642	558	3.27
5	1163	39	8249	4239	893	2.97
6	1395	47	8846	4776	1309	2.77
7	1628	54	9383	5260	1810	2.61
8						
9						
10						
Costs for 260 HP Combine			Plus 24 FT GRAIN PLATFORM		Total	
\$ / ACRE = 76.38/3.87			+ 2.61		22.35	

Table B11: Detailed Costs for the 120 HP TRACTOR

List Price = \$65500.00				Purchase Price = 58950.00		
Fuel Price = \$ 0 .70 / Gallon				Fuel Use = 6.07 Gallons / Hr		
Machine Use = 632.22 Hours / Yr						
Year	Total Hours	Percent of Life	Depreciation	HII *	Total Repair	Cost Per Hour
1	632	5	22204	5895	183	48.99
2	1264	11	24593	9202	750	31.57
3	1897	16	26826	12294	1693	25.77
4	2529	21	28914	15185	3015	22.88
5	3161	26	30867	17889	4713	21.17
6	3793	32	32692	20416	6790	20.04
7	4426	37	34399	22779	9244	19.26
8	5058	42	35995	24989	12075	18.70
9	5690	47	37487	27055	15284	18.28
10	6322	53	38882	28987	18870	17.97

Table B12: Detailed Costs for the 120 HP TRACTOR

List Price = \$65500.00				Purchase Price = 58950.00		
Fuel Price = \$ 0.70 / Gallon				Fuel Use = 6.07 Gallons / Hr		
Machine Use = 315.68 Hours / Yr						
Year	Total Hours	Percent of Life	Depreciation	HII *	Total Repair	Cost Per Hour
1	316	3	22204	5895	46	93.41
2	631	5	24593	9202	187	58.07
3	947	8	26826	12294	422	46.00
4	1263	11	28914	15185	752	39.77
5	1578	13	30867	17889	1175	35.88
6	1894	16	32692	20416	1693	33.18
7	2210	18	34399	22779	2305	31.17
8	2525	21	35995	24989	3011	29.59
9	2841	24	37487	27055	3811	28.31
10	3157	26	38882	28987	4705	27.24

Table B13: Detailed Cost for the 11 FT MOWER

List Price = \$9100.00				Purchase Price = 8190.00		
Machinery Coverage = 300.0 Acres / Yr				Fuel Cost = \$ 1.63 / Acre		
Productivity = 2.6 Acres / Hr						
Annual Use = 115.4 Hours / Yr						
Year	Total Hours	Percent of Life	Depreciation	HII *	Total Repair	Cost Per Hour
1	115	6	3604	819	124	15.16
2	231	12	4062	1232	333	9.38
3	346	17	4475	1603	591	7.41
4	462	23	4847	1938	885	6.39
5	577	29	5181	2239	1211	5.75
6	692	35	5482	2509	1565	5.31
7	808	40	5753	2753	1942	4.98
8	923	46	5996	2972	2343	4.71
9	1038	52	6213	3170	2763	4.50
10						
Costs for 120 HP TRACTOR			Plus	11 FT MOWER	Total	
\$ / ACRE = 21.06/2.6			+	4.50	12.60	

Table B14: Detailed Cost for the 3 FT SPREADER

List Price = \$3000.00			Purchase Price = 2700.00			
Machinery Coverage = 400.0 Acres / Yr			Fuel Cost = \$ 0.0.43 / Acre			
Productivity = 10.0 Acres / Hr						
Annual Use = 40.0 Hours / Yr						
Year	Total Hours	Percent of Life	Depreciation	HII *	Total Repair	Cost Per Hour
1	40	2	1188	270	9	3.67
2	80	4	1339	406	24	2.21
3	120	6	1475	529	44	1.71
4	160	8	1598	639	66	1.44
5	200	10	1708	738	91	1.27
6	240	12	1807	827	117	1.15
7	280	14	1896	908	145	1.05
8	320	16	1977	980	175	0.98
9	360	18	2049	1045	207	0.92
10	400	20	2114	1104	240	0.86
Costs for 120 HP TRACTOR			Plus	3 PT SPREADER	Total	
\$ / ACRE = 21.06 / 10.0			+	0.86	2.97	

Table B15: Detailed Cost for the 40 FT SPRAYER

List Price = \$3000.00			Purchase Price = 2700.00			
Machinery Coverage = 1600.0 Acres / Yr			Fuel Cost = \$ 0.21 / Acre			
Productivity = 20.0 Acres / Hr						
Annual Use = 80.0 Hours / Yr						
Year	Total Hours	Percent of Life	Depreciation	HII *	Total Repair	Cost Per Hour
1	80	5	1188	270	46	0394
2	160	11	1339	406	116	0.58
3	240	16	1475	529	197	0.46
4	320	21	1598	639	287	0.39
5	400	27	1708	738	384	0.35
6	480	32	1807	827	487	0.33
7	560	37	1896	908	595	0.30
8	640	43	1977	980	768	0.29
9	720	48	2049	1045	825	0.27
10	800	53	2114	1104	947	0.26
Costs for 120 HP TRACTOR			Plus	40 FT SPRAYER	Total	
\$ / ACRE = 21.06 / 20.0			+	0.26	1.31	

Table B16: Detailed Cost for the 15 FT DRILL

List Price = \$25400.00			Purchase Price = \$22860.00			
Machinery Coverage = 300.0 Acres / Yr			Fuel Cost = \$ 0.72 / Acre			
Productivity = 5.90 Acres / Hr						
Annual Use = 50.8 Hours / Yr						
Year	Total Hours	Percent of Life	Depreciation	HII *	Total Repair	Cost Per Hour
1	51	3	10058	2286	5	41.2
2	102	7	11339	3438	68	24.74
3	153	10	12491	4475	161	19.03
4	203	14	13528	5408	295	16.03
5	254	17	14461	6248	471	14.12
6	305	20	15301	7004	692	12.78
7	356	24	16057	7684	956	11.76
8	407	27	16737	8297	1266	10.96
9	458	31	17349	8848	1321	10.30
10	508	34	17900	9344	2022	9.76
Costs for 120 HP TRACTOR			Plus	15 FT DRILL	Total	
\$ / ACRE = 21.06/5.90			+	9.76	13.32	

Table B17: Detailed Cost for the 12 Row PLANTER

List Price = 35900.00\$			Purchase Price = \$ 32310.0			
Machinery Coverage = 1000.0 Acres / Yr			Fuel Cost = \$ 0.56 / Acre			
Productivity = 7.57 Acres / Hr						
Annual Use = 132.1 Hours / Yr						
Year	Total Hours	Percent of Life	Depreciation	HII *	Total Repair	Cost Per Hour
1	132	9	14216	3231	164	17.61
2	264	18	16026	4859	718	10.80
3	396	26	17654	6325	1689	8.56
4	528	35	19120	7644	3095	7.46
5	661	44	20439	8831	4948	6.84
6	793	53	21626	9900	7258	6.46
Costs for 120 HP TRACTOR			Plus	12 ROW PLANTER	Total	
\$ / ACRE = 21.06/7.57			+	6.46	9.25	

Table B18: Detailed Cost for the 40 ft FERTILIZER AP.

List Price = \$0.0				Purchase Price = \$ 0.0		
Machinery Coverage = 1000.0 Acres / Yr				Fuel Cost = \$ 0.21 / Acre		
Productivity = 20.0 Acres / Hr						
Annual Use = 50.0 Hours / Yr						
Year	Total Hours	Percent of Life	Depreciation	HII *	Total Repair	Cost Per Hour
1	50	4	0	0	0	0.00
2	100	8	0	0	0	0.00
3	150	12	0	0	0	0.00
4	200	17	0	0	0	0.00
5	250	21	0	0	0	0.00
6	300	25	0	0	0	0.00
7	350	29	0	0	0	0.00
8	400	33	0	0	0	0.00
9	450	37	0	0	0	0.00
10	500	42	0	0	0	0.00
Costs for 120 HP TRACTOR			Plus 40 FT FERTILIZER		Total	
\$ / ACRE = 21.06 / 20.0			+ 0.00		1.05	

Table B19: Detailed Cost for the 11 FT CHISEL PLOW

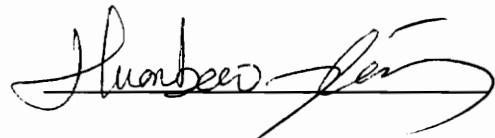
List Price = \$9100.00				Purchase Price = \$ 8190.00		
Machinery Coverage = 300.0 Acres / Yr				Fuel Cost = \$ 1.63 / Acre		
Productivity = 2.60 Acres / Hr						
Annual Use = 115.4 Hours / Yr						
Year	Total Hours	Percent of Life	Depreciation	HII *	Total Repair	Cost Per Hour
1	115	6	3604	819	124	15.16
2	231	12	4062	1232	333	9.38
3	345	17	4475	1603	591	7.41
4	462	23	4847	1938	885	6.39
5	577	29	5181	2239	1211	5.75
6	692	35	5482	2509	1565	5.53
7	808	40	5753	2753	1942	4.98
8	923	46	5996	2972	2343	4.71
9	1038	52	6216	3170	2763	4.50
Costs for 120 HP TRACTOR			Plus 11 FT CHISEL PLOW		Total	
\$ / ACRE = 21.06/2.6			+ 4.50		12.60	

Table B20: Detailed Cost for the 18 ft DISK HARROW

List Price = \$13700.00		Purchase Price = \$ 12330.0				
Machinery Coverage = 1700.0 Acres / Yr		Fuel Cost = \$ 0.87 / Acre				
Productivity = 6.0 Acres / Hr						
Annual Use = 346.3 Hours / Yr						
Year	Total Hours	Percent of Life	Depreciation	HII *	Total Repair	Cost Per Hour
1	346	17	5425	1233	406	4.16
2	692	35	6116	1854	1348	2.72
3	1039	52	6737	2414	2697	2.32
4	1385	69	7296	2917	4406	2.15
5	1731	87	7800	3370	6444	2.07
6						
7						
8						
9						
10						
Costs for 120 HP TRACTOR			Plus	18 FT DISK HARROW	Total	
\$ / ACRE = 21.06 / 6.00			+	2.07	6.36	

Vita

Huanbao Xiong was born in Jiangxi Province, P. R. China, on August 1964. He received a bachelor degree in Department of Electrical Engineering in 1984, and a Master of Science in Department of Computer Science in 1986. From 1986 to 1992, he worked as a computer engineer in Aerospace Ministry of China in Beijing. In 1992, he was enrolled as a graduate student at Department of Biological Systems Engineering at Virginia Tech.

A handwritten signature in black ink, appearing to read 'Huanbao Xiong', with a stylized flourish at the end.

Huanbao Xiong