ANALYSIS OF THE EFFECTS OF SELECTED VARIABLES ON CORN HARVESTING SYSTEMS UTILIZING SIMULATION AND DYNAMIC PROGRAMMING

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

ROBERT ALEXANDER MILLIGAN

1971

ANALYSIS OF THE EFFECTS OF SELECTED VARIABLES
ON CORN HARVESTING SYSTEMS UTILIZING
SIMULATION AND DYNAMIC PROGRAMMING

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Agricultural Economics

1971

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ACKNOWLEDGEMENTS

The author wishes to acknowledge his co-major professors, Dr. Larry J. Connor and Dr. David L. Armstrong, for their invaluable advice and constructive criticism. Without their assistance and encouragement this thesis would have been only a dream.

Appreciation is also expressed to Dr. J. B. Holtman and Dr. L. R. Pickett for their guidance in the development of this study and to George Perkins for his help in development of the model.

Thanks are expressed to Dr. Dale E. Hathaway and the Department of Agricultural Economics for the financial assistance and the facilities that made my Masters program possible.

Finally, the author expresses a special word of sincere thanks to his wife, Karen, for her patience, understanding and encouragement.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table		Page

Table		Page

Appendix
Table | Page

Appendix
Table Page

Appendix
Table | Page

Append

Table

C. 12.

D. 1.

D. 1.

Appendix
Table | Page

LIST OF FIGURES

Figure | Page

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CHAPTER I

INTRODUCTION

Regardless of the type of management during the planting and growing seasons, the farm manager has only losses to show for his efforts if he fails to harvest his crop. Many management decisions must be made prior to the harvest seasons. Should the present harvester be traded for a new one? Should a larger harvester be purchased? Should new or larger equipment be purchased to handle the crop? Many more decisions are necessary during the harvesting season. When should harvest commence? How much labor should be hired to shorten the harvesting time? Farm manager's answers to these questions, and many more, affect the income he and his family receive. Wrong answers can result in large quality losses, or in the case of corn harvest the crop may remain in the field long after the snow has fallen.

As farm firms continue to increase in size, the importance of the harvesting system increases. With increased size, investments in the harvesting system necessarily increase. Combines now cost $16,000 and up (1). Transportation and drying equipment are becoming increasingly important and expensive. Also, with increased acres, the pressure to complete harvest without large losses increases. The number of potential harvest days remains constant regardless of the acreage to be harvested. A day lost because of a breakdown or because the hired man skipped work or because of a poor management decision becomes even more expensive.

Many different factors affect the answers to the above mentioned questions and the farm manager's income. What is the effect of size in good years and in bad? Are the price of the output and the yield the most important variables as farm managers commonly believe? What is the effect on harvest and income of the temperature and of rainfall? How does a farm manager decide when to trade for a new harvester? The importance of these and other factors must be determined before a farm manager can make optimal decisions.

The reader has probably already realized that the above decisions involve different time periods. Some of the decisions affect only the present harvest period while the effect of other decisions is felt for several years. Two different time periods are of primary importance for the harvesting system. The first is the individual harvesting period. The second time period must involve several years since many decisions, notably machinery replacement, affect harvest for several years.

For the individual harvest period, which is referred to as the short-run, the land, buildings, machinery and acreage to be harvested must be assumed fixed. Since only the harvest period is being studied, the conditions previous to harvest must be assumed. These conditions include potential yield, grain moisture content, and the condition of the crop especially with respect to lodging and field conditions. In this time period the decisions concerning when to harvest are crucial. The factors of importance are the number of acres to be harvested, the price for the crop and its yield, the weather conditions and the grain moisture content.

For the period of several years, which is referred to here as the long-run, the major decision relevant to the harvesting system alone is the choice of and/or replacement of the harvester. Decisions regarding size and other machinery must consider more than the harvesting system. Optimum replacement policy is very important and relatively complex.

In 1968 farm managers enrolled in TelFarm, the Michigan State University farm records project, spent an average of $8,998 or 20.5 per cent of their total expenses on power and machinery (2). The investment in machinery averaged $21,994 or 13.22 per cent of the average total investment on these farms (3). Of course not all of this machinery was owned or used in harvest; however, the expensive machines--combines, tractors, trucks--are used exclusively or at least substantially during harvest. The importance of machinery is not limited to one type of farm. Saginaw Valley cash crop farms that were enrolled in TelFarm in 1968 incurred $10,856 in machinery expenses which was 23.19 per cent of the total expenditures on these farms. These same farms had a machinery investment of $22,245 which was 7.99 per cent of their total investment (4). For cash grain farms the machinery expenses were $8,792 or 26.05 per cent of the total expenditures with a machinery investment of $19,758 (5). The importance of machinery is only slightly less on livestock farms. Cattle feeding farms enrolled in TelFarm in 1968 incurred 19.89 per cent of their expenses on machinery (6) and specialized southern dairy farms spent 19.49 per cent of their expenses on machinery (7).

Farm managers need a more accurate criterion than the one explained by a farm manager recently, "We trade when repair costs get high." In order to minimize costs over time the criterion should be to use the policy which minimizes average yearly cost using an appropriate discount rate. Determining this optimum policy is not easy since repair costs, trade-in value and various obsolescence charges must be included in the calculation. Since in most instances the farm manager is trading for a non-identical machine, further problems are encountered. In the long-run, as in the short-run, many variables affect this optimum policy.

Objectives

Many decisions made by the farm manager are important in determining his income. A simulator and a replacement model are used as a techniques of analysis to achieve the following objectives:

1. To determine the effect of selected variables on corn harvesting systems for individual harvesting periods (short-run).

2. To evaluate the effect of selected variables on machinery replacement for the harvest system for corn (long-run).

3. To determine the effect on the optimum replacement policy of changes occurring in the individual harvesting period, and to determine the effect of changes in the optimum replacement policy on income from the individual harvesting period.

The overall objective of this study is to determine the effect of various variables on the harvesting system. Knowledge of these effects can be used by farm managers to improve their decision-making abilities during harvest. Since the simulator as presently developed simul

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simulates southern Michigan conditions for corn harvest and uses input-output coefficients typical of this area, this study is most concerned with farm managers in southern Michigan who raise corn either as a cash grain or for feed.

The short-run variables are studied using the corn harvest simulator (8). The following nine variables are studied extensively using the simulator:

1. Loss due to failure to complete harvest.
2. Size of enterprise.
3. Hours in the work day.
4. Grain moisture criterion.
5. Opportunity cost of the operator of the harvester.
6. Average temperature.
7. Additional rainfall.
8. Expected price.
9. Potential yield.

The results from using several values for each of the above variables are used to determine the short-run effects of each of these variables on income from the harvesting system.

Changes in long-run variables effect the optimum replacement frequency. The magnitude of the effect of the following seven variables is analyzed:

1. The source of the cost data.
2. The shape of the repair cost function.
3. The number of hours the machine is used.
4. The level of machinery management.
5. The rate of obsolescence.

6. Increasing cost to purchase a new machine.

7. The interest rate.

This magnitude is measured using a dynamic programming replacement model.

The third objective is attained by considering the effect of changes in variables in each time period on the other time period. The effect of changes in replacement policy on the individual harvesting period is evaluated. Conversely, the effect of short-run changes on the optimum replacement policy is analyzed.

Organization of the Thesis

The remainder of this thesis is concerned with the following main ideas. Chapter II develops a conceptual framework with a look at relevant economic theory, simulation and replacement theory. Chapter III is devoted to a detailed look at the model. The results from studying the variables affecting the individual harvesting period are contained in Chapter IV. Chapter V contains the analysis of these short-run results. The results of the variables affecting machinery replacement are then presented in Chapter VI. The analysis of these long-run results and an integration of the short-run and the long-run are presented in Chapter VII. Chapter VIII contains the summary and conclusions. The implications for further research are presented in Chapter IX.

Footnotes

1. According to machinery dealers in the Lansing, Michigan area farm managers pay approximately $16,000 for a model 4400 John Deere combine with a four-row corn head.

2. Hepp, Ralph E. Michigan Farm Business Analysis Summary--1968 Data, Research Report 95, Michigan State University Agricultural Experiment Station, East Lansing, October 1969, P. 4.

3. Ibid., P. 5.

4. Kyle, Leonard R. TelFarm Business Analysis Summary for Saginaw Valley Cash Crop Farms, 1968, Agricultural Economics Report 122, Department of Agricultural Economics, Michigan State University, East Lansing, June 1969, P. 2.

5. Harsh, Stephen B. TelFarm Business Analysis Summary for Cash Grain Farms, 1969, Agricultural Economics Report 133, Department of Agricultural Economics, Michigan State University, East Lansing, August 1969, P. 4.

6. Kyle, Leonard R. TelFarm Business Analysis Summary for Cattle Feeding Farms, 1968, Agricultural Economics Report 135, Department of Agricultural Economics, Michigan State University, East Lansing, June 1969, P. 2.

7. Brown, L. H. and John Speicher, TelFarm Business Analysis Summary for Specialized Southern Dairy Farms, 1968, Agricultural Economics Report 137, Department of Agricultural Economics, Michigan State University, East Lansing, June 1969, P. 2.

8. The simulator is being developed under a Michigan Agricultural Experiment Station project titled "Analysis of Agricultural Production Systems" by a multidisciplinary task force. Present members of the task force are Dr. J. B. Holtman, Assistant Professor, Agricultural Engineering; Dr. L. K. Pickett, Assistant Professor, Agricultural Engineering; and Dr. L. J. Connor, Associate Professor, Agricultural Economics. Dr. D. L. Armstrong, Associate Professor, Agricultural Economics and Assistant Dean of the College of Agriculture and Natural Resources was a member until he became Assistant Dean on August 1, 1970.

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CHAPTER II

A CONCEPTUAL FRAMEWORK

Several areas of static economic theory are needed to provide a background for the actions of the farm firm. In order to understand how a simulator can be used to improve the farm manager's knowledge of the harvesting system, simulation or system theory is developed as it relates to the corn harvest simulator. Assuming that the farm manager is a profit maximizer, how does he determine his optimum replacement policy? This question is answered by elucidating the relevant aspects of replacement theory. To illustrate the workings of this theory, several replacement models are examined. The replacement model used in this study is described in detail to illustrate how the model determines the optimum replacement policy. In this chapter these areas of theory are used to construct a conceptual framework for studying the harvest system.

Economic Theory

Several areas of static economic theory of the firm are developed in order to understand what decision rules a farm manager should use to maximize income from his harvesting system. In order to understand why a farm manager's decision would be different in the short-run and the long-run, the length of run theory is presented. Since minimizing cost is a major contributor to profit maximization, the cost theory of the firm is outlined. The theory of asset fixity is introduced to answer questions related to asset acquisition and disposal.

In order to avoid confusion and confine the discussion to a relevant area, two assumptions are made. The first is to assume perfect competition at all times. This assumption means that no matter how many inputs the farm manager purchases or how many outputs he sells, his actions will have no effect on the prevailing price. This assumption is realistic with the sizes of farm firms studied. The second assumption is that the farm managers are strict profit maximizers. In general, this assumption is realistic; however, other goals usually have some influence on the farm managers decisions. These other goals are extremely difficult to quantify.

Intermediate level economic theory differentiates between the short-run and the long-run. The short-run is defined as any period of time in which there are certain inputs whose level of usage cannot be altered even with a large change in output. All costs are considered as either fixed costs, which must be borne, or variable costs. Additional units of variable inputs should be purchased as long as that unit costs less-than the value of its corresponding addition to output, i.e., until the marginal value product of the additional output equals the price of the input. In the long-run all inputs are variable; additional units should be added until the value of the additional output equals the cost of the additional input.

More advanced economic theory, particularly production economics, indicates that the length of run is more complex than simply short-run or long-run. The concept of fixed inputs is again basic to the theory. Common sense indicates that anywhere from none to all of the inputs may be

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may be fixed depending upon the relevant time period and the stage of the production process. Thus, simply using short-run and long-run is an oversimplification.

Before proceeding, some notation must be adopted. Y's will represent outputs and X's will indicate inputs. The equation:

$$Y = f\ (X_1,\ X_2, \ldots, X_n)$$

indicates that the level of output of Y is a function of the level of the inputs $X_1, \ldots, X_n$. All units of each input and each output are assumed to be homogeneous. As indicated above, the length of run is a function of the number of fixed inputs. Therefore, this notation is adopted:

$$Y = f\ (X_1,\ X_2, \ldots\ X_d, | X_{d+1}, \ldots,\ X_n)$$

with X_1, X_2, ..., X_d being variable inputs and X_{d+1}, ..., X_n being fixed inputs. The | (slash) will always mark the division between variable and fixed inputs--all inputs to the left are variable; all inputs to the right are fixed.

The shortest possible length of run is the one in which all inputs are fixed:

$$Y = f\ (0, | X_{d+1},\ \ldots\ X_n)$$

while the longest has all inputs variable:

$$Y = f\ (X_1,\ X_2, \ldots, X_d, | 0).$$

This latter length of run with no variable inputs was called the long run in the simple dichotomy. In this study the short-run is represented by the single harvest period. Its production function could be represented by:

$$Y = f\ (X_1,\ X_2, | X_3,\ X_4,\ X_5)$$

where Y is the yield of corn in a particular year, X_1 and X_2 (variable inputs) are

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inputs) are the harvesting criteria, and X_3 and X_4 and X_5 (fixed inputs) represent machinery, land and the state of the system prior to the harvest. The long-run is represented by a period of several years so that machinery is a variable input to the farm manager. In this length of run Y is average yield.

Since the concept of costs will be important in this thesis, the effect of the length of run on the cost structure must be discussed. The following seven cost functions form the basis for this discussion:

1. Total Fixed Cost = TFC = $\Sigma P_{xi} X_i$, i = d+1, ... n
2. Total Variable Cost = TVC = $\Sigma P_{xi} X_i$, i = 1, ..., d
3. Total Cost = TC = TFC + TVC
4. Average Fixed Cost = AFC = $\frac{TFC}{Y}$
5. Average Variable Cost = AVC = $\frac{TVC}{Y}$
6. Average total cost = ATC = AFC + AVC
7. Marginal cost = MC = the additional cost of producing the last (marginal) unit of output.

The cost per unit of output is at a minimum where MC = ATC. In Figure 1 this cost minimizing point is at output "a" with average cost "b." If the price of the output y is "d," additional units of output should be produced until output "c" is reached. At this point, MC = MR, and profit is a maximum.

Figures 2-4 illustrate the effect of the length of run on the cost functions average total cost and marginal cost. Figure 2 shows the average total cost (ATC_1) and the marginal cost (MC_1) for the production function $Y = f(X_1, | X_2, X_3)$. Note the steepness of the average total cost and marginal cost curves. For the case with two variable

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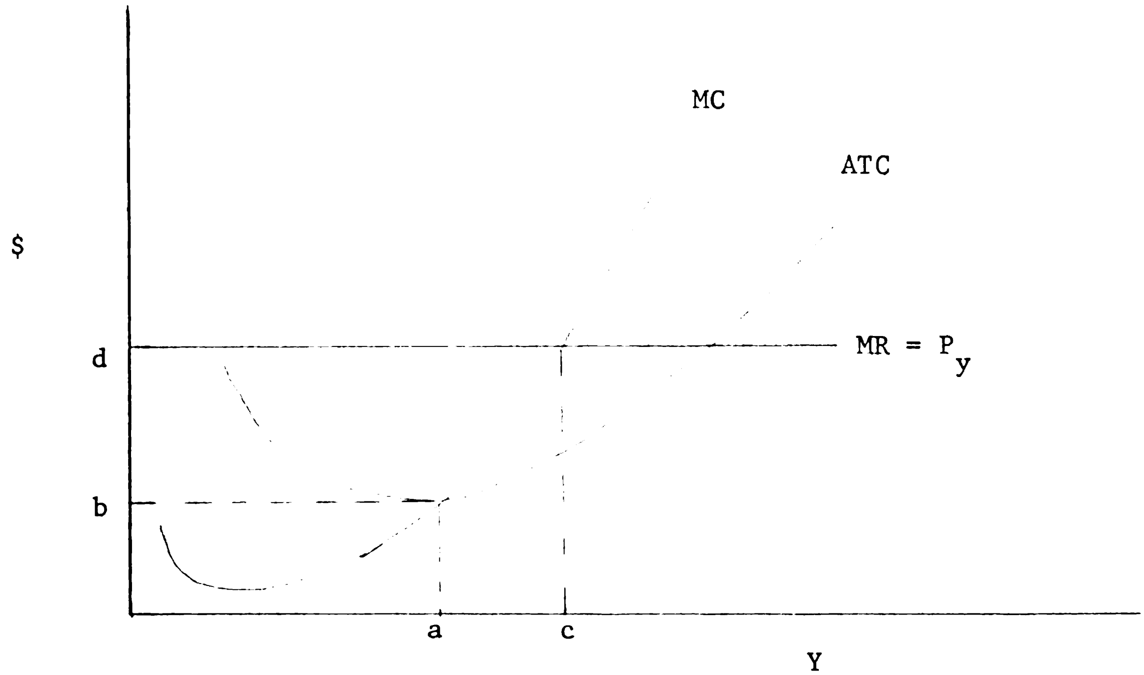

Figure 1. Cost of Production Diagram

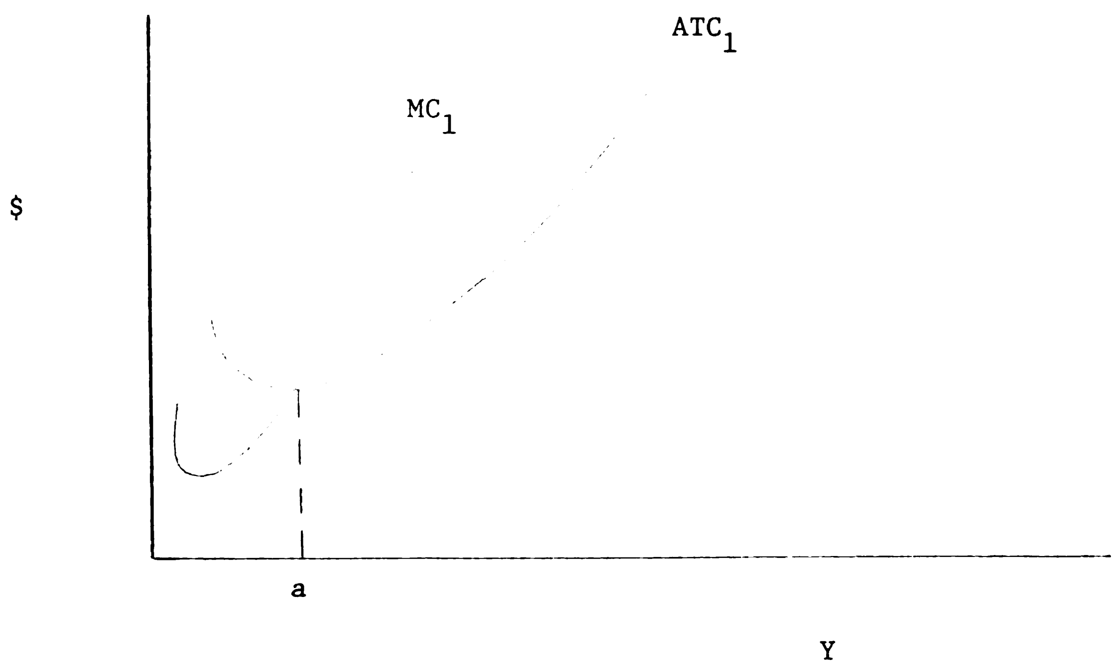

Figure 2. Cost of Production with One Variable Input

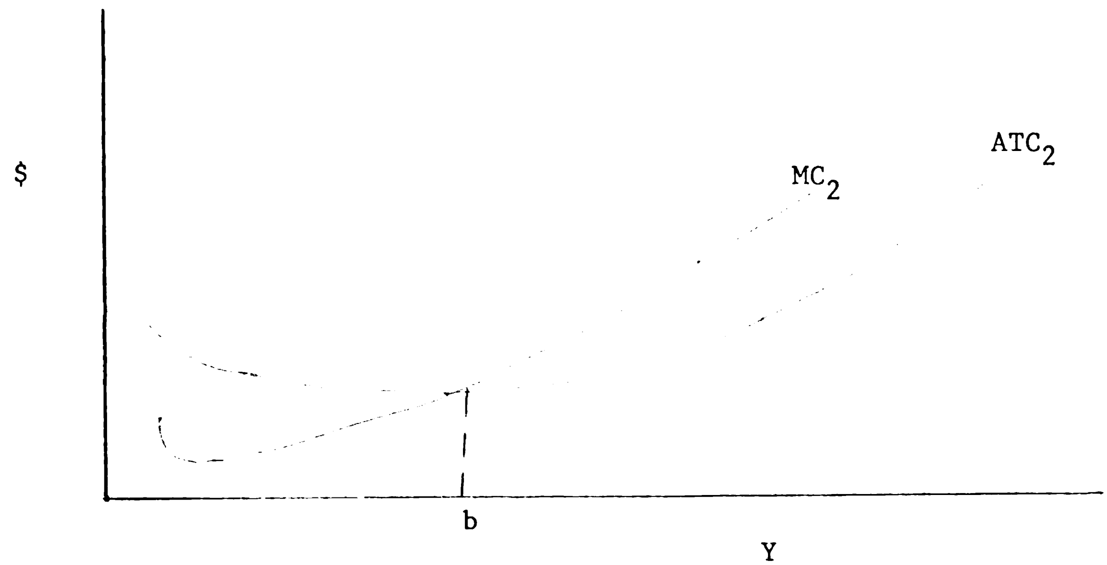

Figure 3. Cost of Production with Two Variable Inputs

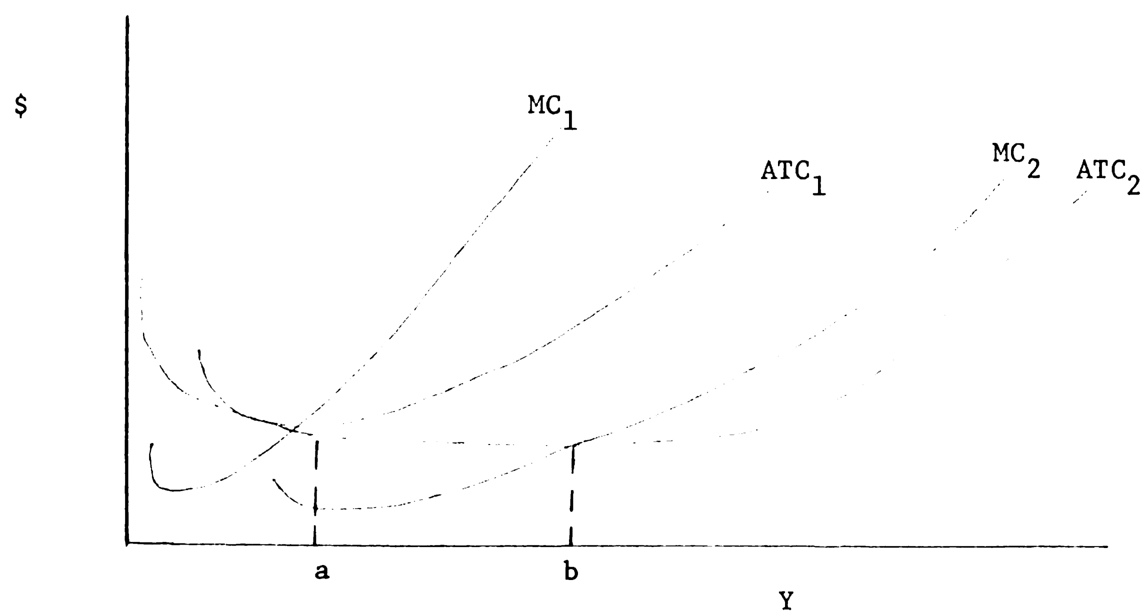

Figure 4. Cost of Production with One and Two Variable Inputs

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inputs $[(Y = f(X_1, X_2, |Y_3)]$, Figure 3 illustrates the average total cost (ATC_2) and the marginal cost (MC_2). The increased flatness of these curves should be observed. Figure 4 superimposes the two previous diagrams. Note once again the increased flatness of the ATC_2 and MC_2 with two variable inputs. This flattening of the cost curves continues as more inputs become variable. The increasing flatness explains why a wider range of outputs must be considered by the farm manager as more inputs become variable. The usual method for increasing the number of variable inputs is to expand the planning horizon.

One further concept must be added in order that the theoretical conditions approach those faced by the farm manager. This concept is the distinction between acquisition and salvage prices of fixed assets. Acquisition price is the cost of purchasing a fixed asset while salvage price is the price that would be received if the fixed inputs were to be sold. These prices represent acquisition and salvage price of the same fixed input at a point in time, not the new price and the scrap price of the input.

At this point, the term marginal value product must be introduced. The marginal value product (MVP) is the value of the increase in output corresponding to a one unit increase in an input. The theory says that additional units of an input should be used as long as the MVP of the input is greater than its cost.

Using the above definitions, the absolute fixity of any input can be defined as any point where its MVP is less than its acquisition price or greater than its salvage price. In the following diagram levels of input usage less than "A" should result in purchase of the input until point A is reached. If input usage is beyond point B, mits

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units of the inputs should be sold at salvage value until point B is reached. For levels of usage between points A and B, the inputs are absolutely fixed although the MVP's from the inputs are not enough to cover acquisition cost except at Point A.

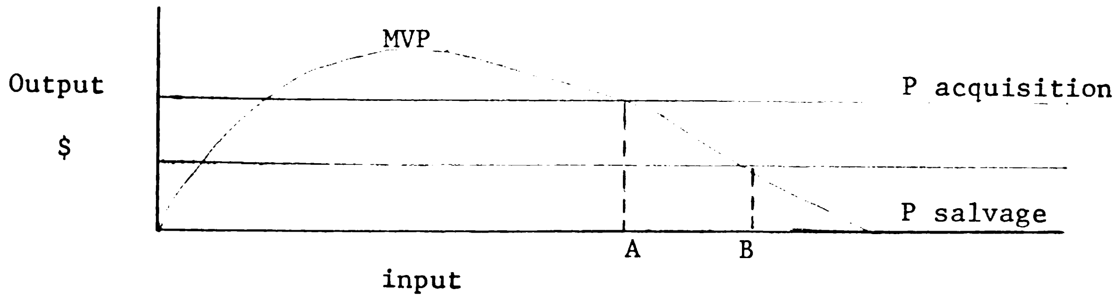

Figure 5. Asset Fixity Diagram for One Variable Input

Economic theory enables one to calculate the yearly cost of inputs whose life exceeds one year or inputs that are fixed in terms of the yearly production period. This calculation allows a manager to compare these inputs with those that are variable for the single production period. To illustrate, assume an input with a useful life of L years and no change in technology (1)

X = Fixed input

P = Price of one unit of X

i = Interest rate

C = present value of an infinite cost stream

then:

$$C = PX + \frac{PX}{(1+k)^{L}} + \frac{PX}{(1+i)^{2L}} + \ldots$$

with the first term representing the cost of the initial purchase, the second term representing the discounted cost L years later, etc.

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$$C = PX\ (1 + \frac{1}{(1+i)^{L}} + \frac{1}{(1+i)^{2L}} + \ldots)$$

$$C = PX\ (1 + c^{-Li} + e^{-21i} + \ldots)$$

$$C = PX\ \frac{(1)}{1-e^{-Li}}$$

to convert this present value to a yearly cost simply multiply by the interest rate:

$$C = PX\ \frac{(1)}{1-e^{-Li}}\ i = \frac{iPX}{1-e^{-Li}}$$

One can think of this process as depositing a sum C in the bank so that the interest would cover the yearly cost.

Simulation

The use of simulation as a research technique has become more and more common throughout the last two decades. A specific description is difficult if not impossible because of its general applicability; however, the following remark should be helpful. Morgenthaler (2) says, "to 'simulate' means to duplicate the essence of a system or activity without actually attaining reality." Morgenthaler concludes that simulation is appropriate whenever the scientific method cannot be used for prediction and estimation. Its steps are (3):

1. Close observation of the physical phenomenon.
2. Creation of a theory or model which explains the observation.
3. Prediction of observables from the theory by using mathematical or logical deduction.
4. Performance of experiments to test the validity of the model.

Whenever these steps cannot be completed, completion can be accomplished by simulating the system.

As is true of any research technique, simulation has advantages and disadvantages (4,5). The principle advantages are:

1. Simulation makes possible the study of very complex systems.

2. It makes possible more adequate study of decision-making with less reliance on mathematical models.

3. It provides new approaches for studying the aggregation problem.

4. Simulation is the most effective method for studying problems under uncertainty.

5. It can be more easily used without high levels of mathematical proficiency.

6. Simulation solutions are more easily understood by non-technical personal.

On the other hand, several disadvantages can be recognized:

1. It is very easy to build one's biases into the simulation model.

2. Simulation is not an optimizing technique.

3. Parameters may be extremely difficult to estimate.

4. Specialization within some fields including economics may be encouraged.

5. Simulation can be time consuming and expensive.

Simulation can be separated into two types--analog and digital (6). Analog simulation uses a model to represent the real physical world. The only requirement is that the important characteristics of the original system must be retained. Although this requirement does not restrict it to scaled-down models, analog simulation will not be used in this thesis. On the other hand, digital simulation using computer facilities is very appealing and will be used extensively. The use of hybrid simulation using both analog and digital simulation is growing rapidly. All references to simulation will henceforth imply digital simulation.

Depending upon the circumstances, a simulation can be determinate or stochastic. Deutsch (7) says, "A determinate model is one for which a unique input stimulus to any of the subsystems will always yield a corresponding unique output stimuli. . . . On the other hand, a stochastic model of a system can be formulated so that when an input stimulus is applied, the model will on its own accord, make a random choice from among a set of permissible system parameters before generating the output stimulus." A determinate system is studied by perturbing the inputs. A stochastic system should be used when decision makers actions are to be studied. A large sample is needed to determine an accurate average.

Two techniques commonly used in simulation are gaming and Monte Carlo methods (8). When gaming is used, the players, usually managers, are an integral part of the system being modeled. Monte Carlo methods integrate probability theory, into the simulation. This method is usually used when the action chosen is a somewhat random decision to be made from a set of alternatives.

Any simulation project can be broken into four steps: problem definition, mathematical modeling and simulation, model refinement and testing and model application. The relationship among these steps is shown in Figure 6 (9). As the diagram indicates, feedback is an important aspect in this process. Time spent in defining one's problem very carefully and critically will usually result in great time-saving in the following steps. In the second step, a simulation

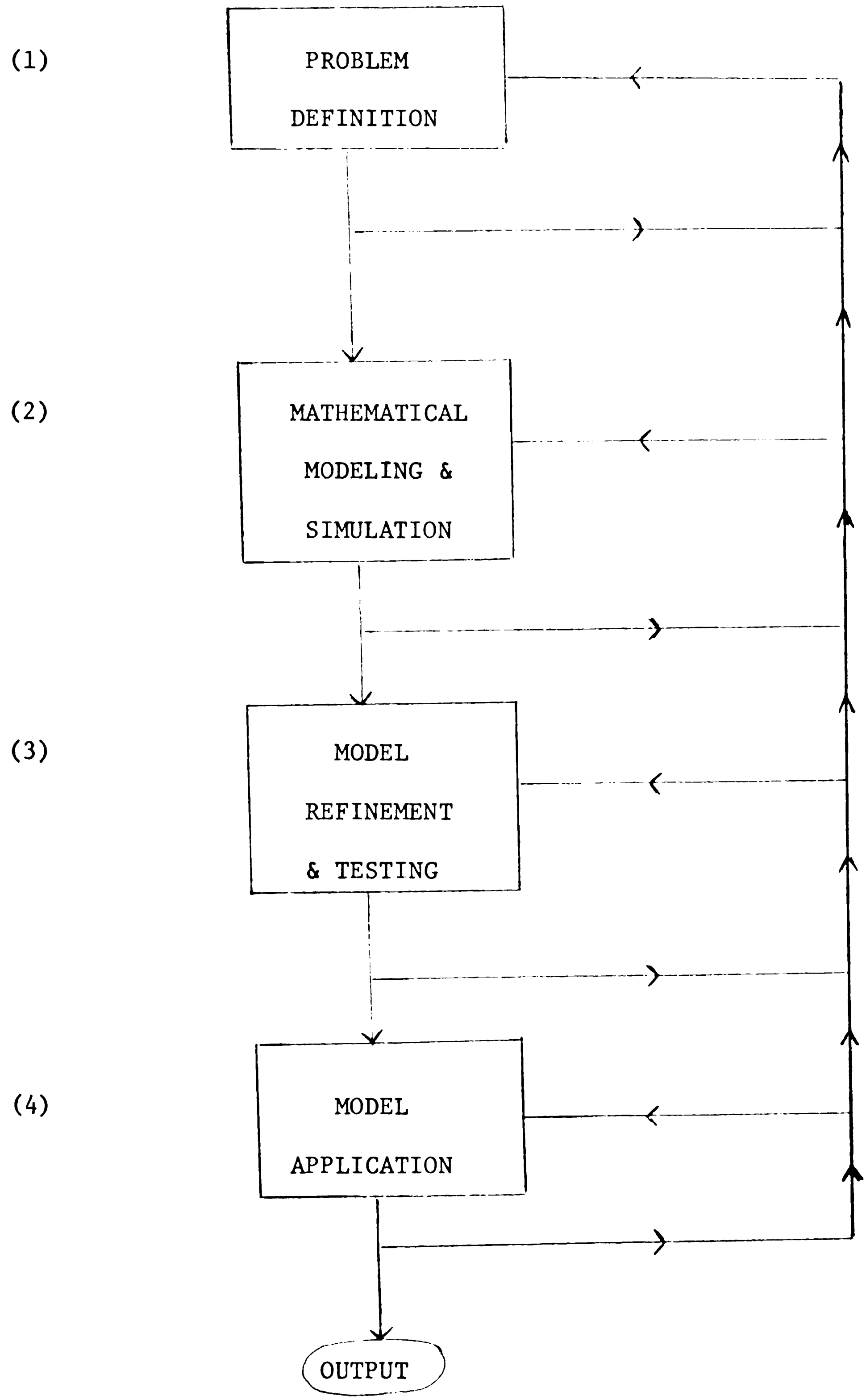

Figure 6. Computer Simulation as an Interative Problem Solving Process

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model is developed that crudely represents the system being simulated. The third and fourth steps comprise what is called sensitivity analysis. This analysis is a process of testing and refining the model so that it accurately represents the real work and is ready for application as a problem-solving technique.

At this point the reader may be asking how can simulation help a farm-manager with his harvesting system. There are two ways. The first is that researchers can use the simulation model to increase their understanding of the harvesting system. They can then provide the farm manager with better advise. Although the cost of the farm manager would be greater, the second way is for the farm manager to use the model to simulate his own farm business. By simulating alternative decisions he would then be able to improve his management decisions.

Replacement Theory

Replacement theory can be dissected into two parts. One part concerns the replacement of items that fail while the other concerns items that deteriorate. This study is concerned exclusively with items that deteriorate.

When discussing replacement policy in either the short-run or the long-run, the objective is cost minimization. When keeping a used machine, the costs include repairs both minor and major, inefficiency with respect to time and performance and technological obsolescence. The cost for trading is the difference between the purchase price of the new machine and the trade-in value of the used machine plus the cost of repairs in the first year when needed to complet

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In this context a short-run decision is one in which the decision to keep or trade is based solely upon the upcoming harvesting period. The manager will trade only if he expects the used machine to cost more in repairs and inefficiencies than the total cost of trading. Using this criteria most machinery would have a relatively large life span especially since the cost of inefficiency is usually underestimated.

In the long-run a much longer time horizon is used so that cost can be minimized over time. The manager must now take into consideration the near certainty that repair and inefficiency costs will be less next year and in future years, if he trades this year. One could still think of this decision as one between the cost of keeping the used machine versus the cost of trading in one year if he added to the cost of keeping the used machine the opportunity cost of not having a new machine. There are, however, better methods of minimizing long-run costs.

Kletke (10) states that when a machine is to be replaced by an exact duplicate, the replacement should occur when the average cost reaches its minimum. At this point marginal cost which is the cost each additional year equals the average cost. In Figure 7 point a represents the optimum replacement time. If replacement occurred at a, the yearly cost would be shown by point c.

Figure 8 illustrates the procedure for determining the optimum time to replace with a different machine. MC_0 and ATC_0 are the marginal cost and the average total cost for the machine the farm manager

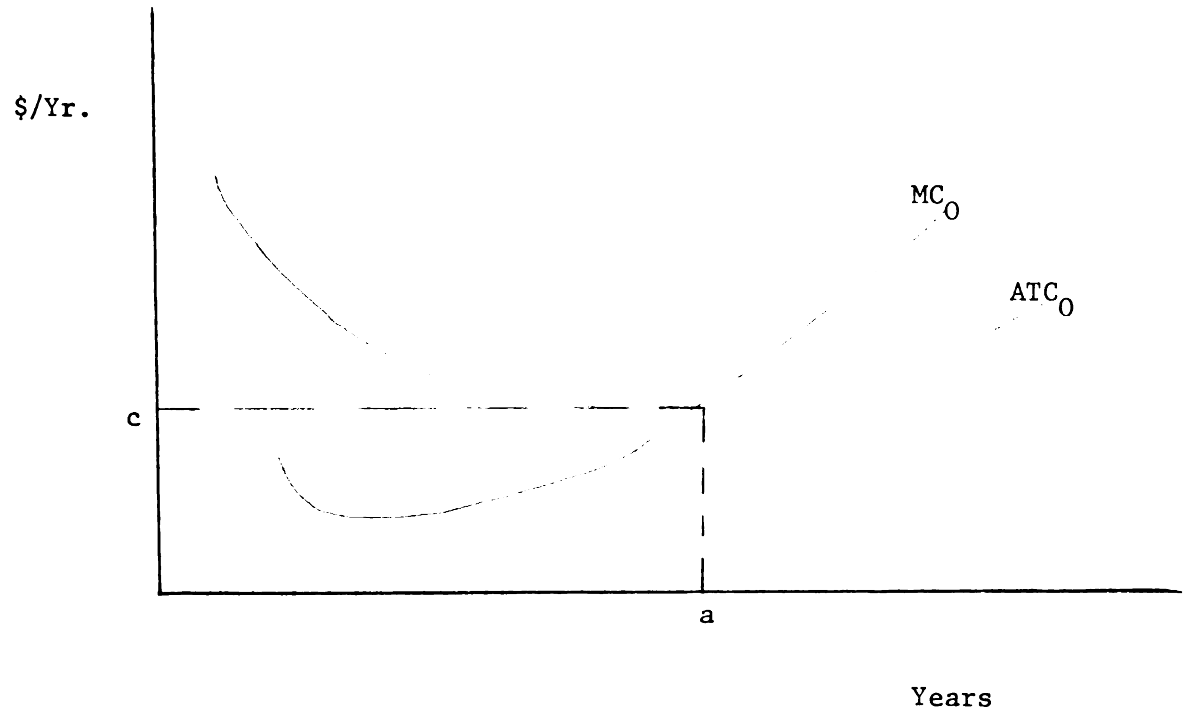

Figure 7. Optimum Replacement with a Duplicate Machine

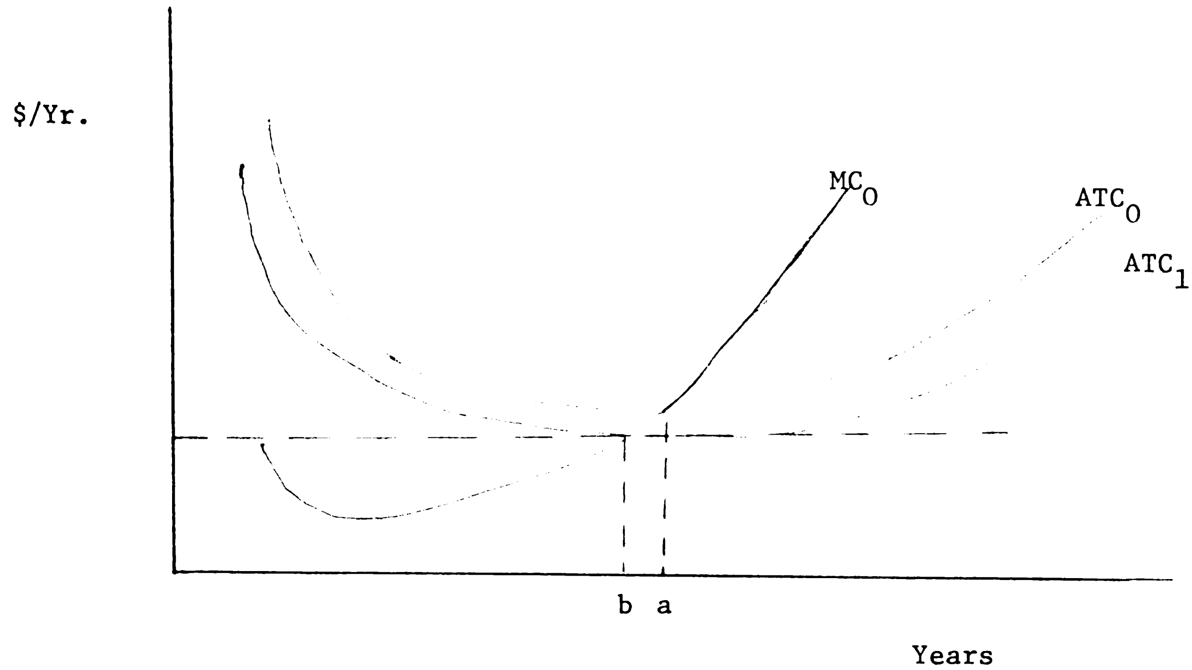

Figure 8. Optimum Replacement with a Different Machine

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is using presently. ATC_1 is the average total cost for the machine the manager is contemplating buying. The farm manager should replace when the current yearly cost (MC_0) exceeds the minimum average cost for the machine to be purchased (ATC_1). Point b in Figure 8 is therefore the optimum time to replace.

This approach of replacing whenever the current yearly cost exceeds the average cost of the replacement appears adequate. A major problem arises however; this method does not consider time preferences. In order to equate a dollar's expense today with a dollar's expense a year from today, the latter must be discounted. Discounting is neglected completely.

Churchman, Achoff and Arnoff (11) correct this deficiency using a similar criteria. One should replace when the yearly cost of keeping the used machine becomes greater than the weighted average of previous costs. This criterion can be expressed mathematically as follows: trade when:

$$C_{n+1} > \frac{(A+C_1 + \frac{C_2}{1+r} + \ldots + \frac{C_n}{(1+r)^n}}{n}$$

with

A = Acquisition cost

C_i = Cost in year i, i = 1, 2,...,n+1

r = Interest rate

this procedure assumes that all costs are incurred at the beginning of each period (year). This procedure corrects the discounting problem but implicitly assumes that the replacement will be an identical machine.

The above two procedures can easily be combined to provide a criterion for replacement with a different machine and including discounting. This criterion would be to replace the machine when its yearly cost exceeds the weighted average of expected cost for the new machine. Mathematically trade when:

$$C_{n+1} > \frac{A_1 + B_1 + \frac{B_2}{(1+r)} + \frac{B_3}{(1+r)^2} + \ldots + \frac{B_n}{(1+r)^{n-1}}}{n}$$

with

A = Acquisition cost of the machine to be purchased

B_i = Cost for keeping in year; the machine to be purchased, $i = 1,2,\ldots,n$

C_{n+1} = Cost of keeping the used machine another period

r = Interest rate

More sophisticated models using more advanced mathematics and the computer can be used. These models incorporate the replacement theory explained above. Models of this type will be discussed in the following section.

Replacement Models

In this section several models built around the long-run replacement theory, presented in the previous section, will be presented. Only models that could be useful in machinery replacement will be surveyed. Three models using the criterion presented explicitly but in more involved terms will be presented. Two models using the theory in a less direct manner will follow. The first of these will use dynamic programming while the second will use dynamic programming and Markov chains. The latter model will be reviewed extensively.

The first model is a straight forward adoption of the model by Baumol (12). He commences with:

$$V = A + \frac{C_1 + C_2 + C_3}{1+r \quad (1+r)^2} + \ldots + \frac{C_n}{(1+r)^{n-1}}$$

where V is the discounted present value of the repair cost for n years. Letting A equal the average yearly outlay for the n years, the following is true:

$$V = A + \frac{A}{1+r} + \frac{A}{(1+r)^2} + \ldots \frac{A}{(1+r)^{n-1}}$$

By geometric progression the following is true:

$$V = A + \frac{A}{1+r} + \ldots + \frac{A}{(1+r)^{-1}} = \frac{[1-(1+r)^n]}{[1-(1+r)]}$$

Solving for A.

$$A = \frac{[1-(1+r)]}{[1-(1+r)^n]} V$$

Using this equation, the optimal long-run replacement policy can be determined by finding the value of n which minimized A, the average yearly outlay for the n years.

Smith (13) presents a much more intricate model which is particularly useful when several replacements will be made within the time horizon. His repair cost function for the Kth machine in a chain of replacements is written E (u,kL,t) where u is the rate of equipment utilization, L is the life of the piece of equipment, kL is the time at which the machine was purchased new and t is the present age of the machine. E is measured in terms of some physical measure such as horsepower, width or number of rows capacity. E(u,kL,t) will usually increase with the age of the machine (t) and decrease as k increases due to technological advance. The author suggests the following simple, linear relationship for a constant u:

$$E(u,kL,t) = E_o - kL + Bt$$

E_o is a constant representing initial repair costs. k is a parameter indicating the yearly reduction in E_o due to technological advance in the form of model changes. B is a parameter indicating the increased repair cost due to increased age.

This function can now be integrated into the full model to calculate a constant annual cost using discounted present value of all purchase cost and repair cost from an infinite chain of continuously improving machines. The general equation used to calculate this cost, w, is:

$$W = r \sum_{k=o}^{00} e^{-rkL} \quad {}^{L}E(u,kl,t)\ e^{-rt}dt + W - Slu,L)e^{-rt}$$

where all variables are defined above. In addition r is the interest rate W is the original cost of the machine and S (u,L) is the salvage value of the machine. e^{-rt} is used to discount the costs for each machine to the date of purchase of that machine E^{-rkL} then discount the cost to the present. Once again the criterion is to solve the model for the L that will minimize W.

Terborgh (14) uses a simplified, linear version of the above equation. He also assumes the utilization rate, w to be constant. His expression is:

$$W = E_o + \left(\frac{\quad +B)}{2}\right) L + \frac{W}{L} + rW$$

where all variables as above. As before, the objective is to minimize w.

A somewhat different model developed by Burt (15) is presented for two reasons. The model uses the alternative method of calculating the revenue from the machine. Secondly the concept of survival probability is introduced. A machine may fail to survive to the next year because of fire, accident, or breakdown that cannot be economically repaired. This probability will be used again later. This model will use discounted present values also.

Before proceeding, the following notation must be introduced (16).

P_t = The probability that an asset of age t will reach age t+1 with normal productivity.

H_t = Net revenue associated with an asset of age t in the absence of replacement due to random causes.

D_t = Cost of replacement cause by random factors.

C_t = Voluntary replacement cost (cost of a new asset minus terminal value of the used one).

$R_t = P_t H_t - (1-P_t) P_t$, i.e., conditional expected value of net revenue during a time interval for an asset of age t (excluding cost of planned replacement.

T = Planned replacement age.

B = $1/(1+i)$, where i is the relevant interest rate for discounting.

The interest rate includes a charge for price uncertainty. As the author indicates, the net revenues are often constant with machinery replacement and can be assumed as such. In this model, all revenues and costs are treated as occurring at the beginning of the period with replacement being made at the end of the period. An infinite planning horizon is assumed as are constant revenue, cost and probability parameters.

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The expected present value of net returns from an asset over its life g(T) must first be calculated. The discounted revenue from any future year will be the net return in that year multiplied by the appropriate discount rate with the product multiplied by the probability of the machine reaching that age. Recalling that $R_t = P_t H_t - (1-P_t) P_t$ includes revenue and probabilities for the final year considered in each term, the equation is:

$$g\ (T) = R_1 + B_{p1} R_2 + B^2{}_{p1\ p}{}^2 R_3 + \ldots$$
$$+ B^{T-2}{}_{p1\ p2\ \ldots\ pT-2} R_{T-1} + B_{p1\ p2\ \cdots\ pT1} (R_T - {}_{pT}C)$$

From this the present value over the infinite time horizon, V(T), can be calculated as follows.

$$V(T) = q\ (T) + E\ (B^{L(T)} V(T))$$

where E indicates expected value. Solving for V(T), the equation is:

$$V(T) = \frac{q(T)}{1-E[B^{L(T)}]}$$

where B is the discount rate.

$$E(B^{L(T)}) = B(1-{}_{p1}) + B^2{}_{p1}\ (1-P) + \ldots$$
$$+B^{T-2}{}_{p1\ p2}\ \ldots\ PT-2\ (1P_{T-1}) + B\ {}_{p1\ p2}\ \ldots\ PT-1$$

As a simplifying device let W_1, W_2, . . ., WT substitute for $1, B_{p1}, B^2{}_{p1\ p2}, \ldots B^{T-1}{}_{p1\ p2} \ldots PT-1$ respectively.

Substituting this equation into the one calculating V(T), yields

$$V(T) = \frac{1}{1-B}\ [\sum_{tsl}^{T} W_t R_t - W_t P_t C_t] / \sum_{t=1} W_t$$

This equation calculates the average discounted present value of expected net revenues. The optimal criterion is then to find the T that maximizes V(T).

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These three models would all derive an optimal solution, however, they all require extensive calculations. The most logical solution is to enlist the aid of a computer. Although used sparingly, dynamic programming is probably the most generally applicable method for solving replacement problems (17). Bellman and Dreyfus (18) present a general model for replacement problems. In this model the cost and returns are calculated for the two alternatives "purchase" and "keep" for each year. A solution is reached via dynamic programming that will maximize the net return. For machinery replacement, however a model using dynamic programming and Markov chains was found to be more relevant to the data available and to provide more flexibility.

This model is explained and used by Howard (19). A user of this model must first decide upon the number of "states" in the model. Each "state" represents a decision period. For machinery replacement each "state" normally represents one year. States are represented by i. For each state the alternatives (k) must be defined. Alternatives can range from "keep" and "trade" (for a new machine) to "keep" and "trade" for a new machine or a used one of any number of ages.

A probability matrix and a reward/cost matrix must be calculated for each state. The probability matrix will contain for each alternative the probability of going from the present state to each of the other states. This probability is called a transitional probability. The reward/cost matrix corresponds to the probability matrix and contains the reward or cost for each alternative of going from the present state to each of the others. The following table represents the model as it w

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as it would appear at this point. Four states with two alternatives each are used for illustration.

state i	alternative k	probability P_{ij}^{k}, $j=1$	$j=2$	$j=3$	$j=4$	reward/cost C_{ij}^{k}, $j=1$	$j=2$	$j=3$	$j=4$
1	1	P_{11}^{1}	P_{12}^{1}	P_{13}^{1}	P_{14}^{1}	C_{11}^{1}	C_{12}^{1}	C_{13}^{1}	C_{14}^{1}
	2	P_{11}^{2}	P_{12}^{2}	P_{13}^{2}	P_{14}^{2}	C_{11}^{2}	C_{12}^{2}	C_{13}^{2}	C_{14}^{2}
2	1	P_{21}^{1}	P_{22}^{1}	P_{23}^{1}	P_{24}^{1}	C_{21}^{1}	C_{22}^{1}	C_{23}^{1}	C_{24}^{1}
	2	P_{21}^{2}	P_{22}^{2}	P_{23}^{2}	P_{24}^{2}	C_{21}^{2}	C_{22}^{2}	C_{23}^{2}	C_{24}^{2}
3	1	P_{31}^{1}	P_{32}^{1}	P_{33}^{1}	P_{34}^{1}	C_{31}^{1}	C_{32}^{1}	C_{33}^{1}	C_{34}^{1}
	2	P_{31}^{2}	P_{32}^{2}	P_{33}^{2}	P_{34}^{2}	C_{31}^{2}	C_{32}^{2}	C_{33}^{2}	C_{34}^{2}
4	1	P_{41}^{1}	P_{42}^{1}	P_{43}^{1}	P_{44}^{1}	C_{41}^{1}	C_{42}^{1}	C_{43}^{1}	C_{44}^{1}
	2	P_{41}^{2}	P_{42}^{2}	P_{43}^{2}	P_{44}^{2}	C_{41}^{2}	C_{42}^{2}	C_{43}^{2}	C_{44}^{2}

This data is then used to calculate the immediate expected return, q_i^k, for each alternative in each state. This calculation is performed as follows:

$$q_i^k = \sum_{j=i}^{k} P_{ij}^k \quad C_{ij}^k .$$

for alternative 1 in state 1 of the above table

$$q_1^1 = p_{11}^1 \, C_{11}^1 - p_{12}^1 \, C_{12}^1 - p_{13}^1 \, C_{13}^1 + p_{14}^1 \, C_{14}^1$$

The maximum (reward) or expected immediate reward minimum (cost) in each state is then determined. This is the optimum policy for the very short run.

A new matrix must now be formed using the transitional probabilities corresponding to the policy chosen above. Assuming that this policy chose alternatives 1, 2, 2, 1 for states 1, 2, 3, 4; this matrix would be used.

$$P = \begin{bmatrix} P_{11}^{1} & P_{12}^{1} & P_{13}^{1} & P_{14}^{1} \\ P_{21}^{2} & P_{22}^{2} & P_{23}^{2} & P_{24}^{2} \\ P_{31}^{2} & P_{32}^{2} & P_{33}^{2} & P_{34}^{2} \\ P_{41}^{1} & P_{42}^{1} & P_{43}^{1} & P_{44}^{1} \end{bmatrix}$$

The corresponding q_i^k values are also needed.

$$q = \begin{matrix} q_1^{1} \\ q_2^{2} \\ q_3^{2} \\ q_4^{1} \end{matrix}$$

the values in the reward/cost matrix are no longer needed since they represent short-run returns.

The value-determination equations are solved next. The equations are:

$$g + V_i = q_i + \sum_{j+i}^{N} P_{ij} V_j \quad i = 1, 2, \ldots, N$$

where N is the number of states. For the policy above the equations would be:

$$g + V_1 = q_1^{\ 1} + P_{11}^{\ \ 1} V_1 + P_{12}^{\ \ 1} V_2 + P_{13}^{\ \ 1} V_3 + P_{14}^{\ \ 1} V_4$$

$$g + V_2 = q_2^{\ 2} + P_{21}^{\ \ 2} V_1 + P_{22}^{\ \ 2} V_2 + P_{23}^{\ \ 2} V_3 + P_{24}^{\ \ 2} V_4$$

$$g + V_3 = q_3^{\ 2} + P_{31}^{\ \ 2} V_1 + P_{32}^{\ \ 2} V_3 + P_{33}^{\ \ 2} V_3 + P_{34}^{\ \ 2} V_4$$

$$g + V_4 = q_4^{\ 1} + P_{41}^{\ \ 1} V_1 + P_{42}^{\ \ 1} V_2 + P_{43}^{\ \ 1} V_3 + P_{44}^{\ \ 1} V_4$$

where g represents the gain from the policy chosen (1, 2, 2, 1 in the example) and the v_i's represent the desirability of reaching state i. One of the v's is set equal to zero and equations are solved simultaneously for g and the other v's. The values for the V's now represent the desirability of going to their respective states relative to the one set equal to zero.

The policy-improvement routine is now used to calculate test quantities to replace the immediate expected return as the criterion for choosing a policy. This equation is used to calculate the test quantities for all alternatives in all states using the original $q_i^{\ k}$'s, $p_{ij}^{\ \ k}$'s and the v_j's from the value determination equations.

$$q_i^{\ k} + \sum_{j=1}^{N} P_{ij}^{\ \ k} V_j$$

For state 1 in the example the equations would be:

$$q_{12}^{\ \ 1} + P_{11}^{\ \ 1} V_1 + P_{12}^{\ \ 1} V_2 + P_{13}^{\ \ 1} V_3 + P_{14}^{\ \ 1} V_4$$

$$q_1^{\ 2} + p_{11}^{\ \ 2} V_1 + p_{12}^{\ \ 2} V_2 + p_{13}^{\ \ 2} V_3 + P_{14}^{\ \ 2} V_4$$

A new policy is now determined by choosing the maximum (reward) or minimum (cost) test quantity in each state.

The probabilities and immediate expected returns ($q_i^{\ k}$) corresponding to this policy will be used to solve value determination equations again to get new test quantities. This iterative process should be contin

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be continued until two consecutive iterations determine the same policy. This policy will then be the optimal long-run policy and will maximize (reward) or minimize (cost) the grain g.

The above model considers all dollars as equal with regard to time. To conform more to reality a discounted process is introduced (20). The process is the same but the equations are altered somewhat. The value determination equations are changed from:

$$g + V_i = q_1 + \sum_{j=1}^{N} P_{ij} v_j, \; i = 1, 2, \ldots, N$$

to

$$v_i = q_i + B \sum_{j=1}^{N} P_{ij} v_j, \; i = 1,2,\ldots,N$$

where B is the discount rate [1/(1 + interest)]. The g has been dropped because the concept of yearly gain or cost g is not relevant with discounting, and the v_i's represent the discounted present value. This system of equations is now solved for all of the v's. The equation in the policy improvement routine is also changed from

$$q_i^k + \sum_{j=1}^{N} P_{ij}^k v_j$$

to

$$q_i^k + B \sum_{i=j}^{N} P_{ij}^k v_j$$

The above model both with discounting and without is the general formula. A number of adjustments are made for use in a specific replacement model. These changes are discussed in the next chapter. One should keep in mind that this model uses the principle shown in Figure 7 that the machine should be replaced when the current yearly cost exceeds the average total cost. When discounting is used, the principle is

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principle is the same with the average cost being calculated using discounting.

Footnotes

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CHAPTER III

THE MODEL USED TO STUDY THE HARVESTING SYSTEM

Based upon the conceptual framework developed in the previous chapter, a method had to be found to evaluate the effect of various variables on the harvesting system in the short-run and the long-run. The method chosen is a computer model consisting of two parts. The first part of the model is a simulator of a corn harvesting system. The simulator is used to analyze the individual harvesting period (short-run). Simulation provides a great amount of flexibility to analyze the chosen variables. Since the simulator as presently designed cannot consider long-run decisions, the second part of the model is the dynamic programming routine with Markov chains described in the previous chapter. This routine is used to evaluate the effect of the replacement of the machines used in the harvesting systems. Each of the parts of the model is described in this chapter.

Corn Harvest Simulator

Three important points must be stressed at the outset. The simulator as presently developed (1) simulates only corn harvest. Because of the manner in which the system is developed, the simulator is only helpful for short-run decision-making. The third points is that the system is completely deterministic.

The simulator is a short-run system since all variables concerning more than one harvest period are enogenously specified. The three long-run items are usually land, machinery and buildings. In this system the number of acres to be harvested is exogenously specified. The machinery to be used as well as its specifications (depreciation, years of use, etc.) is also specified by the person operating the system. Because of the nature of the harvesting system, no buildings are involved. Since the system is not designed to test long-run decision, the simulator is used only for simulating individual harvest periods.

The simulator is completely deterministic, that is there are no random elements. All exogenous variables are therefore given unchanging values. Because the system is deterministic, any set of values for the exogenous variables always determines the same set of output values. Analysis of the variables affecting the harvesting system is therefore conducted by solving the system for each of several values for a specified variable while all other variables are held constant.

In order to simulate only the harvesting system, a starting point must be chosen. This point is September 30. The maximum yield and the moisture content of the grain must be specified. For the first 14 days of October there is no harvest; however, the system updates the soil moisture content and the grain moisture content each day. This updating uses the exogenous variables rainfall, maximum and minimum temperature, wet bulb temperature and open pan evaporation for each day. Starting October 15th the updating continues but harvest can occur if the following conditions are met. The first condition is that the grain moisture content is less than or equal to an exogenously specified level. If this level has been reached, there is harvest if the soil is tractable. The soil being tractable means that the soil is dry enough that the combine can operate in the field.

The harvesting period continues through November 30 for a total of 47 days. All corn that is not harvested during the harvesting period is assumed to be harvested on December 31. This unrealistic assumption is used because the data needed to determine tractability in December is unavailable. The simulator does not contain any drying or storing facilities, so the corn is assumed to be sold the day of harvest subject to drying and hauling charges. A list of the values used for the exogenous variables is contained in Appendix A.

The simulator contains twelve subsystems each performing a specific task. Figure 9 contains a flow diagram showing the interrelationships among the subsystems. Each day starts with subsystem DATE. Prior to and after the harvesting period only the first three subsystems are needed. During harvest all subsystems through COMBIN are used. The final five subsystems are used after harvest is completed to determine expenses and incomes. Each of the subsystems is briefly described below (2):

1. DATE: Establishes the date for each day. This is the starting point for each day's activity.
2. CLIMATE: Reads in the data so that the weather conditions can be established each day.
3. SOILMC: Calculates the daily soil moisture taking into account the moisture in the soil the previous day, rainfall, runoff, evaporation and plant use. This subsystem is not used in December because of lack of data.

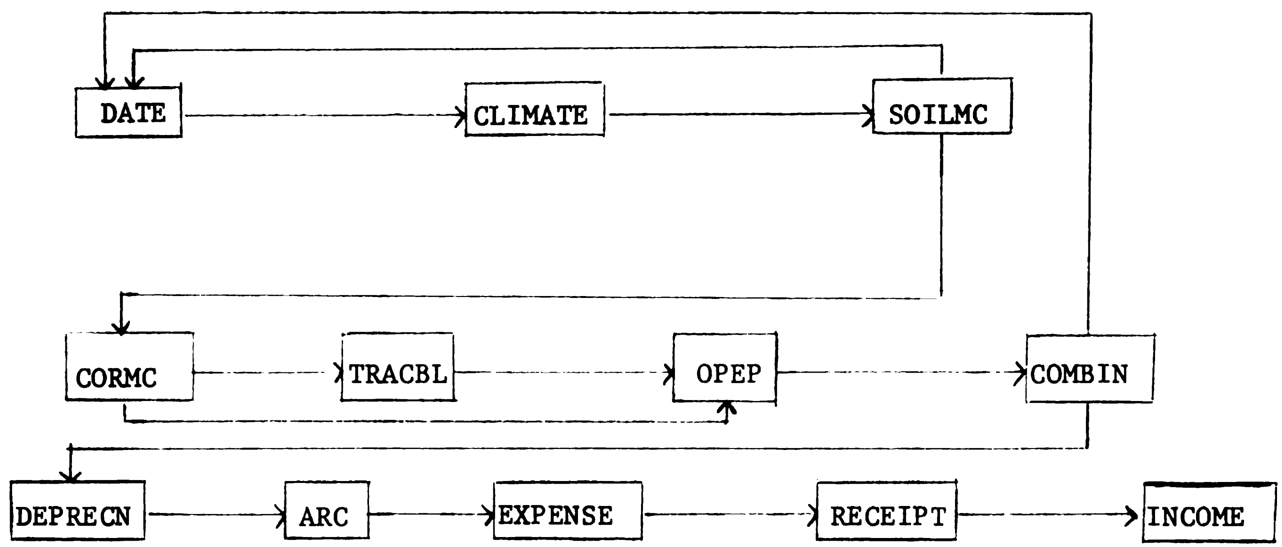


Figure 9. A Flow Diagram of the Corn Harvest Simulator

4. CORNMC: Calculates the moisture content of the corn (grain) each day beginning October 15.

5. TRACBL: Determines the tractability of the soil using the moisture content for each day during the harvest season.

6. OPER: Determines which parts of the farm firm can be harvested daily during the harvesting season and on December 31. The section must be tractable, unharvested and meet maximum grain moisture criterion.

7. COMBIN: Determines yield harvested based upon maximum possible yield minus field losses for as many acres as can be harvested in the given length of day.

8. DEPRECN: Calculates the depreciation for each machine to a maximum of 15 years using straight line, double declining balance, sum-of-the-digits or any of the three with 20 percent additional first year depreciation. A depreciation expense figure is also calculated which eliminates the time differential among the types of depreciation (3).

9. ARC: Calculates the annual repair cost based upon the formula (4):

$$ARC = NC\,[(-.0197X_1 + .0087X_1^2 - .00053X_1^3) + (.02 + .00025X_2)]$$

where:

ARC = annual repair cost

NC = new cost of machine being considered

X_1 = age of machine

X_2 = hours of annual use

10. EXPENSE: Is an accounting subsystem that calculates expenses for each machine as well as the firm including per acre, per hour and per bushel cost where they are appropriate.

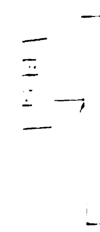
11. RECEIPTS: Calculates the total receipts.

12. INCOME: Combines the values derived in the two previous subsystems to calculate a number of income figures including net cash income, management income, labor income, and return on investment.

Many of the decisions made by the system use more than one of the subsystems. The first seven subsystems are used along with additional exogenous variables to determine the climatological and engineering aspects of the system. The following six major decisions fall into this category:

1. Weather today.
2. Soil moisture budget.
3. Grain moisture content.
4. Tractability.
5. Harvest decision.
6. Harvest performance.

Figure 10 illustrates the sequencing of these decisions for each day. If the harvest decision is affirmative, the harvest performance is then determined.



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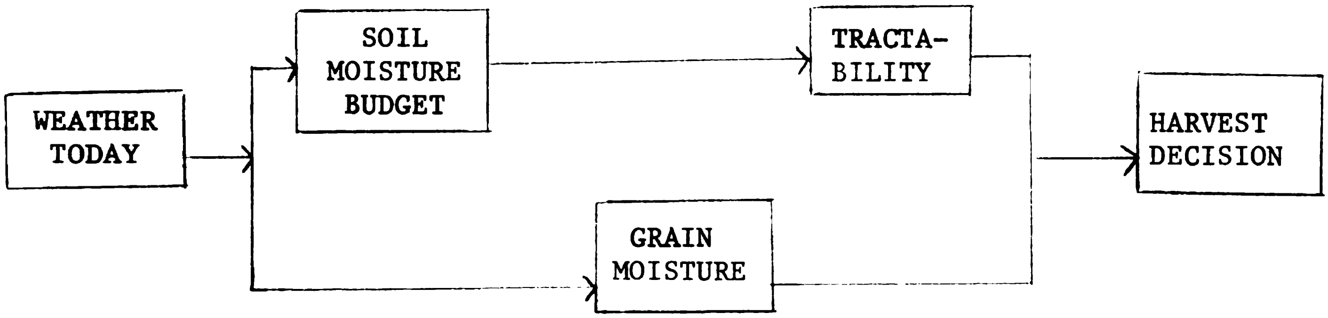

Figure 10. The Sequencing of Daily Decisions

The weather for each day is determined from the precipitation, the maximum and minimum temperatures, the wet bulb temperature and the open pan evaporation for that day provided by the U. S. Weather Bureau. The soil moisture budget establishes the level of moisture in each inch of soil for the first six inches of soil for each day. The procedure used is diagramed in Figure 11.

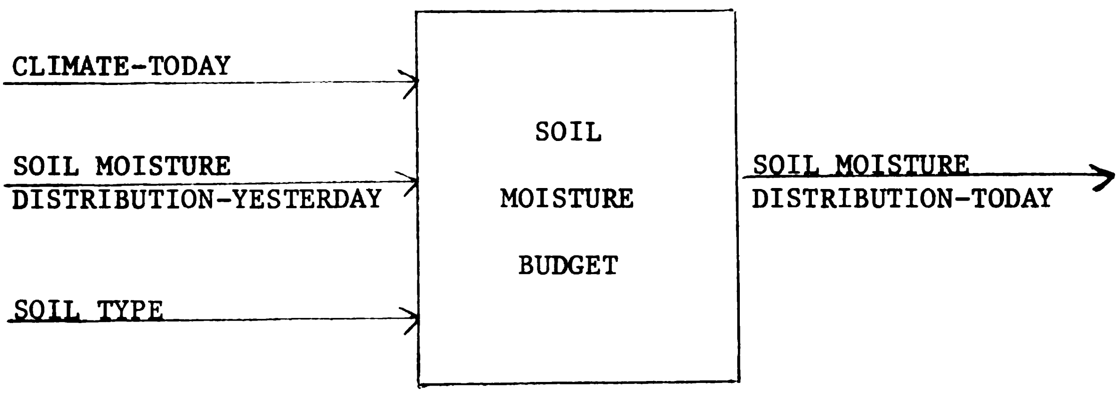

Figure 11. Procedure to Determine Soil Moisture

Once the soil moisture distribution is determined and the soil type is known, the tractability of the soil is determined by that subsystem. At the same time the grain moisture content is calculated based upon the grain moisture content yesterday and the weather today.

Given these calculations, the system can check the tractability and the grain moisture content and make the decision concerning whether to harvest. If the decision is to harvest and harvest has not been already completed, the harvest performance is determined. Figure 12 shows the factors that are needed to calculate the harvest performance and the measure of harvest performance that are calculated.

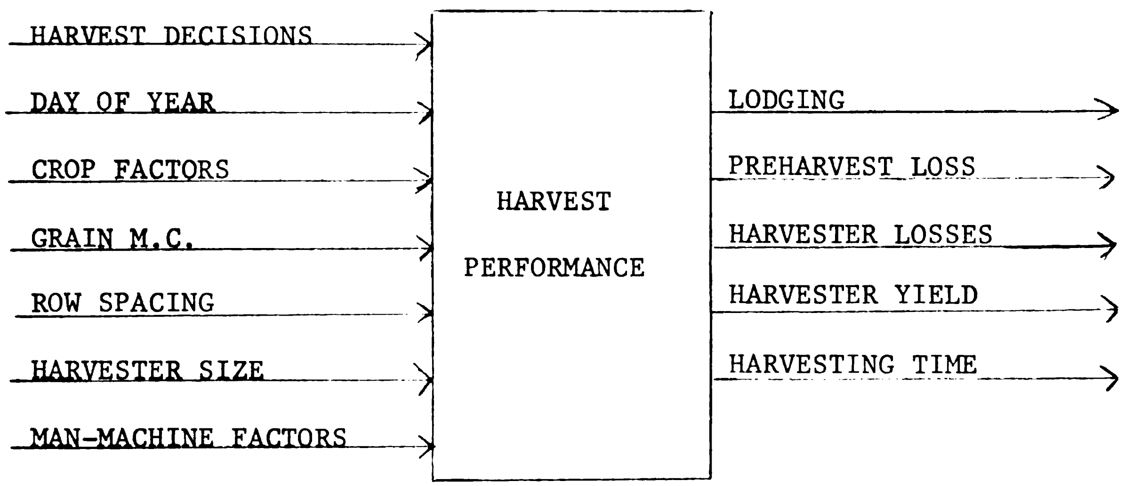

Figure 12. Diagram of the Calculation of Harvest Performance Criteria

For each set of variables the harvesting system is simulated for three years for each of two combines. One combine is a John Deere model 3300 with a two-row corn head costing $12,000; the other is a John Deere model 4400 with a four-row corn head costing $16,000. Both combines are assumed to be depreciated over eight years using straight line with 20 percent additional first year depreciation.

1966-1968 are used as base years. The basic weather data is taken from Monroe County, Michigan for those years. To be consistent corn prices quoted by the Michigan Elevator Exchange for those three years are used. Because only the harvesting system is simulated, a maximum yield as of September 30 must be assumed. This maximum was 150 bushels in 1966, 100 bushels in 1967 and 125 in 1968. These yields are at least close to actual conditions on that date.

A complete list of the exogenous inputs is present in Appendix A. These values are representative of those currently prevailing in Southern Michigan. Some of these values are temporarily changed for analysis purposes.

The Machinery Replacement Routine

The replacement of machinery, particularly the combine, is of crucial importance to the farm manager in managing his harvesting system. This decision is an investment decision rather than an operating decision. Since the simulator can only analyze short-run operating decision efficiently, a machinery investment routine was developed by George Perkins (6) and this author. The machinery replacement routine uses dynamic programming and Markov chains based upon Howard (7). The routine chooses an optimum replacement policy that minimizes the long-run expected costs subject to the conditions prescribed by the operator.

The routine used follows from the theory presented in Chapter II with several adaptations. The major adaptation is that only one conditional probability is used for each alternative. For the alternative "keep" this probability is the probability that the machine will survive until the following state. In this study each state represents one year. The probability of survival to the next state (year) in the last state must be zero. The conditional probability for an alternative involving trading the machine is the probability that the machine traded for will survive to the next state. Since the age of the machine has little or no effect on returns from the combine, cost minimization is used. The cost for keeping the machine includes repairs (both routine and major) plus an obsolescence cost based on age. The cost of trading is the cost of the newly acquired machine minus the trade-in value of the original machine plus repair cost in the next state and obsolescence cost (unless a new machine) for the newly acquired machine.

Although several options can be used, the basic format is the same in each formulation. Each has three subsystems. Figure 13 illustrates with a flow diagram the sequencing of the subsystems.

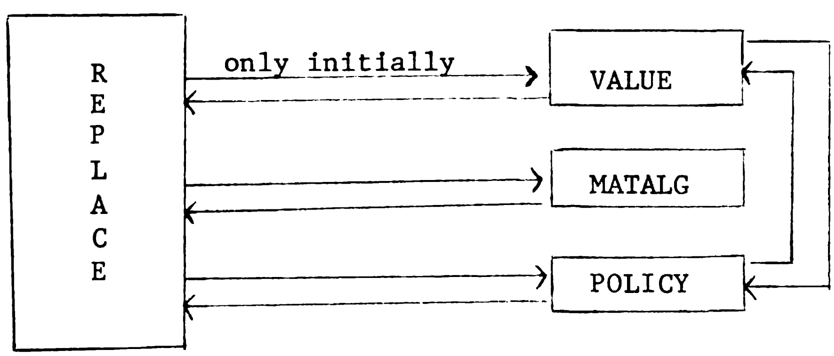

Figure 13. A Flow Diagram of the Machinery Replacement Routine

Each of the subsystems has a specific purpose:

1. VALUE determines which of the alternatives have the smallest immediate expected cost initially and the minimum test quantity thereafter. The p's and g for each of the chosen alternatives are then prepared for simultaneous solution. This subroutine completes most of the value-determination operation.

2. MATALG completes the value determination operation by simultaneously solving the equations.

3. POLICY calculates the new test quantities each iteration (policy-improvement). Subsystem VALUE is called from this subroutine.

Seven states and two alternatives are used. Each state represented one year with the first state representing the decision to keep or trade a one year old machine. The two alternatives are to keep the old machine or to trade for a new machine. Although both the number of states and the number of alternatives could have been moved relatively easily, neither was removed because no significant limitations were imposed by the restrictions. Seven states were more than sufficient to determine an optimal policy, and the data needed to consider trading for used machine was not available at a cost that would justify its use in this study.

As was mentioned above, this model makes available a number of options. The user can present his data in one of two forms. He can simply supply the costs for each of the two alternatives in each of the seven states (years), or he can supply probabilities and corresponding costs for different types of repairs for each alternative. The second option concerns the interest rate. If no interest rate is used, the solution to the simultaneous equations will be six V_i's representing the relative ($V_7 = 0$) desirability of reaching state i and q indicating the annual yearly cost using the optimal policy assuming the user stated in state 1. When using discounting, however, the solutions will be seven V_i's representing the discounted present value of the stream of expenses commencing in state i and using the optimal policy.

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Footnotes

1. The corn harvest simulator was designed in a project titled "Analysis of Agricultural Production Systems," established by the Michigan State Agricultural Experiment Station. The task force included Dr. J. B. Holtman, Assistant Professor, Agricultural Engineering; Dr. L. K. Pickett, Assistant Professor, Agricultural Engineering; Dr. P. L. Armstrong, Associate Professor, Agricultural Economics; and Dr. L. J. Connor, Associate Professor, Agricultural Economics. Dr. Armstrong has since been appointed Assistant Dean, College of Agriculture and Natural Resources.

2. The first eight subsystems were developed by Dr. J. Ben Holtman and Dr. Leroy R. Pickett both Assistant Professors in Agricultural Engineering. The descriptions are the authors.

3. The formula used is:

$$\sum_{i=1}^{N} \text{SL equivalent} - \frac{(\text{dep}_i - \text{SL equiv.})\ \text{tax rate}}{(1 + \text{interest rate})^i}$$

where N is the years of depreciation.

4. Formula developed by Dr. David L. Armstrong, Associate Professor of Agricultural Economics and Assistant Dean College of Agriculture and Natural Resources.

5. These component models were developed by Drs. Holtman and Pickett for a paper "Modeling of Corn Production Systems-A New Approach" delivered by Dr. Holtman at the 1970 Annual Meeting, American Society of Agricultural Engineers, Minneapolis, Minnesota, July 7-10, 1970.

6. George Perkins is a Graduate Assistant and Ph.D. candidate in Agricultural Economics at Michigan State.

7. Howard, Ronal A. <u>Dynamic Programming and Markov Processes</u>, The Technology Press of the Massachusetts Institute of Technology and John Wiley and Sons, Inc., New York, 1960, Especially pp. 54-59.

CHAPTER IV

RESULTS FROM THE SHORT-RUN HARVESTING PERIOD

This chapter specifies the values used for each of the selected variables and presents the results obtained from using the specified sets of variables to simulate the corn harvesting system. These results are needed to determine the effect of these selected variables in the short-run. The format used for studying the selected variables is to simulate three years using yield, grain moisture and weather conditions from 1966, 1967 and 1968. Each of these years has several unique characteristics so that three very different situations are studied. The years are referred to as first, second and third rather than by date since changes in the selected variables make the conditions quite different from those actually occurring. Several important characteristics of the three years prior to any variable changes are presented in Table 1. A complete list of the exogenous inputs is contained in Appendix A.

Nine variables were chosen for study. The nine variables and their initial values are:

1. Loss due to failure to complete harvest during the harvest season -0.00 (1).
2. Size of enterprise - 200 acres.
3. Hours in the work-day--8 hours.

Table 1. Characteristics of the Three Years Used in Studying the Corn Harvesting System

	Unit	Year		
		Year 1	Year 2	Year 3
Maximum yield as of September 30	Bu.	150	100	125
Grain moisture on October 15	Per Cent	36.0	40.3	26.9
Tractability days during harvest[a]	Days	37	16	32
Average price	Dol.	$1.23	$1.06	$.96
Date harvest started[c]	Date	October 28	November 8	October 15
Tractability days after start of harvest	Days	24	8	32

[a]Tractability means the soil is dry enough so the combine can operate in the field. There are 47 days in the harvest period.

[b]Average of price prevailing on harvest days including December 31.

[c]The first tractable day after the grain moisture content reached 30% or below.

4. Grain moisture criterion--harvest can begin when the grain moisture content reaches 30.0 per cent.

5. Opportunity cost of the combine operator's labor--$3.00 per hour (2).

6. Changes in average temperature--temperatures prevailing in 1966-1968 (see Appendix A).

7. The effect of additional rainfall--rainfall in 1966-1968 (see Appendix A) (3).

8. Price--the prices prevailing in 1966-1968 (see Appendix A and Table 1).

9. Potential yield as of October 15 - 1966-1968 (see Table 1).

Table 2 presents the average acreage harvested and several average income figures for the three years. The acreage harvested is that portion of the corn which is harvested during the harvesting period. The acres that are assumed to be harvested December 31 are not included. This definition of the acreage harvested is used throughout the study. Net cash income is the income the farm manager has after paying all cash costs. After he covers depreciation, operator and family labor, and interest on his investment, the remaining income is the return for his management or management income. The $45.00 (4) subtracted from the harvesting income figure covers seed, fertilizer, herbicide, tillage expense, etc. to cover the expenses incurred prior to September 30.

Table 2 quickly illustrates the need for a change in the assumption that all of the corn is harvested. Even when acreage harvested during the harvest period fails to increase with the size of enterprise,

Table 2. Three Year Averages for Different Sizes of Corn Enterprise Using a Two-Row Combine and a

Table 2. Three Year Averages for Different Sizes of Corn Enterprise Using a Two-Row Combine and a Four-Row Combine Assuming all of the Corn is Harvested[a]

Acres	Harvested acres		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acre)	4-row (acre)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
200	168	194	19150	18122	10150	9122	6572	5550	-2428	-3450
300	234	261	28362	27584	14862	14104	11945	10615	-1655	-2875
400	264	328	38320	37477	20280	19447	17362	16078	-636	-1422
500	270	395	47531	47383	25031	24883	22495	21333	-5	-1167
1000	270	480	97420	97292	52470	52521	49550	48723	4550	3723

[a]Corn not harvested during the harvesting period, October 15 - November 30 is assumed to be harvested December 31.

[b]$45.00/acre is subtracted to cover costs previous to harvest.

income continues to increase (or loss of income continues to decrease); furthermore, even with a 1000 acre enterprise, the two-row combine proves more profitable although it only harvests an average of 270 acres during the harvest season. In order to represent the real world more closely, the base value for the loss due to failure to complete harvest during the harvest season was changed to 40 per cent.

Table 3 presents the values used for each of the nine variables. The base value is the value used whenever another variable is being studied. The harvesting system is simulated for all possible combinations of the first three variables-loss, acres and hours--except the second sliding function for loss was only used with 8.0 hours. For the grain moisture criterion the system is simulated using each criterion and each of the sizes of enterprise. For the remaining five variables, the system is simulated for each of the chosen values with 200 and 500 acres. When the results are presented, three year averages are used primarily, with individual years used when a particular year is especially responsive to the changes being made. In order to illustrate the conditions in the years being studied, Table 4 presents the important output figures from each of the output figures with all base values, except the size of enterprise is changed to 500 acres. Similar output for 300, 400 and 1000 acre enterprises is contained in Appendix Tables B. 1, B. 2, and B. 3.

As Tables 1, 4 and 5 illustrate, the first year is extremely profitable. The yield and the price are high and harvesting conditions are very good. The following year is financially disastrous with low yields and extremely unfavorable harvesting conditions. The price is

Table 3. The Values Used for each of the Nine Variables when that Particular Variable was being Studied

Variable	Base Value	Other values
Loss	40%	0, 20%, sliding 1,[a] sliding 2[b]
Acres	200 acres	300, 400, 500, 1000
Hours	8.0	10.0, 12.0, 14.0
Grain moisture	30%	28%, 32%, sliding[c]
Opportunity cost	$3.00/hour	2.00, 5.00, 8.00, 12.00
Additional rainfall	Normal[d]	+1" on October 15, November 1, November 15
Temperature	Normal[d]	-1°, -5°, +1°, +5°
Price	Normal[d]	-.$01, -.05, -.10, +.01, +.05, +.10
Yield	Normal[d]	-10 bu., +10 bu.

[a]Loss is 5 per cent for the first section not harvested, 6 per cent for the second, etc.

[b]Loss is 5 per cent for the first acre not harvested, 5.5 per cent for the second acre, 6.0 per cent for the third, etc.

[c]Harvest can start if grain moisture content fell below .26 before October 21, .28 before October 29, .30 before November 4, .32 before November 11, .34 before November 18, .40 before November 25.

[d]Normal refers to actual conditions for 1966-68. These values are used as a base for years one, two and three.

Table 4. Income and Expense Figures for Each of the Three Years for a Two-Row and a Four-Row Combine Using Base Values

Income or Expense	1st year 2-row	1st year 4-row	2nd year 2-row	2nd year 4-row	3rd year 2-row	3rd year 4-row	Average 2-row	Average 4-row
Total receipts ($)	34456	34477	15842	19081	21075	20750	23791	24769
Machinery expense[a]	2833	3486	2758	3391	2812	3473	2800	3450
Total cash expense[a]	8015	8449	5157	5681	5841	6341	6337	6823
Total expense[a]	20018	21134	17074	18250	17671	18795	18254	19393
Net cash income[a]	26441	26028	10668	13400	15235	14408	17448	17946
Management income[a]	14437	13343	-1249	831	3404	1955	5531	5377
Net cash income[b]	17441	17028	1668	4400	6235	5408	17448	8946
Management income[b]	5437	4341	-10249	-8169	-5596	-7045	-3469	-3623
Acres harvested	200	200	102	184	200	200	167	195
Date harvest completed[c]	11/19	11/05	--	--	11/02	10/26	--	--
Hours combine used	131	72	128	70	124	69	128	70

[a]From harvesting only.

[b]Includes all expenses--$45.00/acre prior to October 1.

[c]When completed.

Table 5. Income and Expense Figures for Each of the Three Years for a Two-Row and a Four-Row Combine Using Base Values with a 500 Acre Enterprise

Income or Expense	1st year 2-row	1st year 4-row	2nd year 2-row	2nd year 4-row	3rd year 2-row	3rd year 4-row	Average 2-row	Average 4-row
Total receipts ($)	71791	86228	33254	36510	50937	58507	51994	60415
Machinery expense[a]	3836	4316	3713	4226	3746	4261	3765	4267
Total cash expense	15966	18737	11579	11976	12723	13580	13422	14766
Total expense[a]	41470	44921	36999	38045	38053	39533	38839	40833
Net cash income[a]	55824	67492	21674	24534	38214	39928	38571	43985
Management income[a]	30321	41307	-3743	-1535	12884	13974	13154	17916
Net cash income[b]	33324	44992	-826	2034	15714	17428	16071	21485
Management income[b]	7821	18807	-26243	-24035	-9616	-8520	-1430	-4584
Acres harvested	295	500	105	185	410	500	270	395
Date harvest completed[c]	--	11/29	--	--	--	11/10	--	--
Hours combine used	341	183	328	182	320	174	330	180

[a]From harvesting only.

[b]Includes all expenses--$45.00/acre prior to October 1.

[c]When completed.

slightly below the average for the three years. Although conditions during the harvest period are excellent, the third year is unprofitable, though better than the second year, because the yield is only average and the price is extremely low. Conditions in the three year period are slightly below average.

In the following pages the results from changing the values of the variables are discussed for each variable individually. In some instances more than one variable will have a value other than its base value. Whenever any value other than the base value is used, the new value is specified.

Loss

Whenever corn is not harvested by the first of December, the possibility exists that the corn will never be harvested or will not be harvested until spring. The simulator as previously developed included losses from lodging, maturity, machine speed, etc. but did not include loss from failure to complete harvest. Furthermore, tractability data was unavailable for December so all corn not harvested by December 1 was assumed to be harvested on December 31. For this study the assumption that the remaining corn is harvested December 31 is retained since the tractability data is still unavailable, but five alternative functions are used to simulate the possibility of harvest not being completed. The first function assumes no possibility of loss while the second and third functions assume that 20 per cent and 40 per cent of the corn harvested on December 31 is lost. The fourth and fifth functions incorporate increasing losses per unit as the number of unharvested acres increases. With the first of the two functions, 5 per cent of the first section harvested in December is lost (the total acreage is divided into 100 equal sized sections), 6 per cent of the second section is lost, etc. The fifth function assumes that 5 per cent of the first acre harvested December 31 is lost with an additional 0.5 per cent is lost on each succeeding acre not harvested. The two functions are the same for 200 acres only.

Tables 6 and 7 summarize the results by three year averages for 200 and 500 acres respectively. By comparing the two tables the reader can easily observe the increased importance of the loss function as the size of the enterprise increases. This relationship is also apparent in similar tables for 300, 400 and 1000 acre enterprises that appear in Appendix Tables B. 4, B. 5 and B. 6.

Size

To study the effect of changes in size, five sizes of enterprise are used--200, 300, 400, 500 and 1000 acres. 200, 300, 400 and 500 acre enterprises certainly could be harvested with one combine although 400 and 500 acres are extremely large enterprises for a two-row combine. The 1000 acre enterprise is used more to determine the effect of such a large size than because the size is realistic since farm managers with that many acres of corn would have a larger combine or more than one combine. The use of only one combine and no custom hire is assumed in this study.

When considering the results, the reader should remember that the relative magnitude of the changes in size of enterprise is larger than the magnitude of changes in other variables. This difference occurs for two related reasons. First, changes in the size of

Table 6. Three Year Averages of Acres Harvested and Income from a 200 Acre Corn Enterprise Using Alternative Loss Functions for the Acres not Harvested by December 1 for a Two-Row and a Four-Row Combine

Acres	Harvested acres[d]		Net cash income from harvesting		Net cash income[e]		Management income from harvesting		Management income[e]	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
No loss	168	194	19050	18120	10150	9122	6572	5550	-2228	-3450
20% loss[a]	168	194	17969	17982	8969	9033	6052	5464	-2948	-3536
40% loss[a]	168	194	17448	17944	8448	8946	5531	5377	-3469	-3623
Sliding #1[b]	168	194	17748	18080	8748	9082	5830	5513	-3170	-3487
Sliding #2[c]	168	194	17748	18080	8748	9082	5830	5513	-3170	-3487

[a]20% and 40% respectively of the corn that could be harvested December 31 is lost due to the possibility that the corn can never be harvested.

[b]5% is lost from the first section not harvested by December 1 with an additional 1% being lost for each section not harvested.

[c]5% is lost from the first acre not harvested by December 1 with an additional .5% being lost on each succeeding acre not harvested.

[d]Harvested acre means the acres harvested prior to December 1.

[e]Includes $45.00 per acre to cover expenses prior to harvest.

Table 7. Three Year Averages for Acres Harvested and Income from a 500 Acre Corn Enterprise Using Alternative Loss Functions for the Acres not Harvested by December 1 for a Two-Row and a Four-Row Combine

Acres	Harvested acres		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
No loss	270	395	47531	47383	25031	24883	22595	21331	-5	-1167
20% loss[a]	270	395	43407	45694	20887	23194	18883	19624	-3617	-2874
40% loss[a]	270	395	38571	43981	16071	21481	13155	17916	-9345	-4584
Sliding #1[b]	270	395	40517	44327	18017	21827	15107	18258	-7397	-4242
Sliding #2[c]	270	395	33549	41371	11049	18871	8132	15302	-14368	-7200

[a] 20% and 40% respectively of the corn that could be harvested December 31 is lost due to the possibility that the corn can never be harvested.

[b] 5% is lost from the first section not harvested by December 1 with an additional 1% being lost for each section not harvested.

[c] 5% is lost from the first acre not harvested by December 1 with an additional .5% being lost on each succeeding acre not harvested.

enterprise are much larger than changes in other variables. Second, the farm managers have the power to change the size of their enterprise. With the other variables being studied the manager can either make changes within a rather small range, or he has no power to make changes.

Table 8 illustrates the effect of the alternative sizes of enterprise on average income. For all sizes of enterprise, increasing acreage decreased management income although the other income figures increased; however, management income remains somewhat constant until the two-row combine exceeds 300 acres and the four-row combine exceeds 500 acres. To illustrate further the effect of size on income, Table 9 presents management income for each year for the various sizes of enterprise. The picture is somewhat different for each of the three years, with management income increasing in the first year until the two-row exceeds 300 acres and the four-row exceeds 500 acres. In the second year management income becomes increasingly negative as size increases. In this second year the management income from harvesting is negative in every case except for the four-row with 200 acres. The third year behaves in a similar fashion to the three year averages. Tables in Appendix B illustrate further the effect of changes in size of enterprise. Appendix Tables B. 7, B. 8 and B. 9 illustrate the effect of size with a 20 per cent loss function and the two sliding functions. Tables B. 10, B. 11 and B. 12 show the effect of size with 10, 12 and 14 hour work days.

Tables 10 and 11 portray the effect of increases in acreage on machinery expenses. Table 10 illustrates the savings in machinery

Table 8. Three Year Averages of Acres Harvested and Income from Different Sizes of Enterprises with a 40 Per Cent Loss on the Corn not Harvested by December 1

Acres	Harvested acres[a]		Net cash income from harvesting		Net cash income[b]		Management income from harvesting		Management income[b]	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
200	168	194	17448	17946	8448	8946	5591	5377	-3509	-3623
300	234	261	26125	26447	12625	12947	9709	9376	-3791	-4122
400	264	328	32887	25147	14887	17147	11970	13578	-6030	-4422
500	270	395	38571	43981	16071	21481	13155	17916	-9345	-4584
1000	270	480	65515	75276	20515	30276	17599	26708	-27401	-18296

[a] Harvested acres means acres harvested prior to December 1.

[b] Includes $45.00 per acre to cover expenses prior to December 1.

Table 9. The Effect of Corn Acreage on Management Income for the Individual Years for Each Combine[a]

	First Year		Second Year		Third Year	
Acres	Two-row (dol.)	Four-row (dol.)	Two-row (dol.)	Four-row (dol.)	Two-row (dol.)	Four-row (dol.)
200	5437	4343	-10249	-8169	-5596	-7045
300	10110	8905	-15566	-13411	-5917	-7861
400	8835	13697	-20932	-18634	-5993	-8331
500	7821	18807	-26243	-24035	-9616	-8526
1000	1646	15082	-53425	-50481	-30426	-19469

[a]40 per cent of the corn harvested after the harvesting season is assumed lost.

Table 10. Three Year Averages of Expenses for the Two-Row and the Four-Row Combines by Corn Acreage[a]

Acres	Machinery expense		Percentage of total expense		Machinery expense per acre		Machinery expense per hour	
	2-row (dol.)	4-row (dol.)	2-row (%)	4-row (%)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
200	2801	3450	15.34	12.79	14.00	17.25	21.95	49.02
300	3116	3718	12.29	13.96	10.39	12.39	16.11	35.03
400	3438	3990	10.69	11.81	8.60	9.98	13.18	28.04
500	3765	4267	9.69	10.45	7.53	8.53	11.44	23.80
1000	5410	5691	7.43	7.65	5.41	5.69	8.03	15.42

[a]Assumes an eight hour work day and a 40 per cent loss on all corn not harvested by December 1.

Table 11. The Three Year Average Composition of Machinery Expenses by Per Cent for a Two-Row and a Four-Row Combine as the Size of the Corn Enterprise Increases[a]

	Fuel cost		Repair cost		Depreciation expense		Interest on investment		Insurance		Housing	
Acres	2-row (%)	4-row (%)	2-row (%)	4-row (%)	2-row (%)	4-row (%)	2-row (%)	4-row (%)	2-row (%)	4-row (%)	2-row (%)	4-row (%)
200	8.08	7.16	20.03	15.04	47.77	51.71	20.06	21.74	2.01	2.17	2.01	2.17
300	11.04	10.00	24.36	17.81	42.94	47.98	18.04	20.17	1.80	2.02	1.80	2.02
400	13.50	12.51	27.93	20.23	38.92	44.71	16.39	18.80	1.64	1.88	1.64	1.88
500	15.54	14.72	31.00	22.36	35.54	41.81	14.93	17.58	1.49	1.76	1.49	1.76
1000	22.10	22.26	40.65	30.14	24.71	31.35	10.39	13.18	1.04	1.32	1.04	1.32

[a]Assume an eight hour work day and a 40 per cent loss on all corn not harvested by December 1.

cost per acre and per hour as well as relative to total expenses with increases in size. The distribution by per cent of the six types of machinery expenses is shown in Table 11 for the five sizes of enterprise. With increases in size the variable expenses--fuel cost and repair cost--increase relative to the fixed costs--depreciation expense, interest on investment, insurance and housing.

Length of Work Day

In contrast to nearly every other crop, corn harvest is not restricted to the hours of the day when no dew is present. This fact makes the length of the work-day an important variable. In this study 8, 10, 12 and 14 hour days are used. 12 and 14 hour days would certainly require hired labor or operations with more than one operator. The same labor rate was charged for all hours. Under some circumstances a farm manager would have to be charged higher rates for the additional hours.

Table 12 and 13 indicate the effect on acres harvested and on income of the alternative lengths of the work-day for 200 and 500 acres respectively. These tables show that whenever a longer work-day increases the acres harvested, the income is increased. Table 14 illustrates the effect of the length of the work day on management income in each year for 500 acres. Once again increased work-hours increases income except where harvest has already been completed. Harvest is completed with the four-row combine in the first and third year with any of the lengths for the work day considered but never completes harvest during the harvest season in the second year. Although the two-row never completes harvest during the harvesting season in the

Table 12. The Effect on the Average Acres Harvested and on Average Income of Increasing the Length of the Work Day for a Two-Row and a Four-Row Machine with 200 Acres of Corn[a]

Hours	Acres harvested[b]		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
8	168	194	17448	17944	8448	8946	5531	5377	-3469	-3623
10	176	200	17565	17980	8565	8980	5648	5410	-3352	-3592
12	186	200	17725	17839	8725	8839	5808	5270	-3192	-3730
14	194	200	17935	17716	8935	8616	6018	5048	-2982	-3852

[a]A loss of 40 per cent is used on all acres not harvested before December 1.

[b]This is the acres harvested prior to December 1. The remaining corn is assumed to be harvested December 31.

Table 13. The Effect on the Average Acres Harvested and on Average Income of Increasing the Length of the Work Day for a Two-Row and a Four-Row Machine with 500 Acres of Corn[a]

Hours	Acres harvested[b]		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2 row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
8	270	395	38571	43981	16071	21481	13075	17916	-9345	-4584
10	330	410	41151	44011	18651	21511	14784	17942	-7743	-4558
12	365	425	42651	44168	20151	21668	17134	18099	-5266	-4401
14	395	440	43915	44359	21415	21859	18498	18290	-4002	-4210

[a] A loss of 40 per cent is used on all acres not harvested before December 1.

[b] This is the acres harvested prior to December 1.

Table 14. The Effect of the Length of the Work Day on Management Income for Each Year for 500 Acres

Length of Work Day (hours)	First year		Second year		Third year	
	Two-row (dol.)	Four-row (dol.)	Two-row (dol.)	Four-row (dol.)	Two-row (dol.)	Four-row (dol.)
8	7821	18807	-26243	-24035	-9806	-8704
10	11802	18097	-25403	-22317	-6887	-9688
12	16089	17640	-24559	-20834	-7516	-10265
14	19424	17362	-23524	-19294	-8096	-10957

second year, harvest can be completed in the first year by working 14 hours per day, and completion occurs in the third year with ten or more hours per day. Appendix Tables B. 13, B. 14 and B. 15 contains tables similar to Tables 12 and 13 for 300, 400 and 1000 acres. The Appendix also contains tables showing the effect of the different lengths of work-days on 200 and 500 acres with a 20 per cent loss function (Tables B. 16 and B. 17) and the first sliding function (Tables B. 18 and B. 19).

Grain Moisture Criterion

The grain moisture content is crucial to farm managers deciding when to commence harvest. Four criteria are considered for determining when to start harvest as related to the grain moisture. The first three criteria state that the grain is ready to be harvested as soon as the grain moisture content falls below 28, 30 and 32 per cent. If the moisture content returns to a level above the criterion, harvest stops. The fourth criterion once again has a sliding feature in that the maximum content increases as the harvesting season progresses. Specifically, the harvest could commence if the grain moisture content fell below 26 per cent before October 21, 28 per cent before October 28, 30 per cent before November 4, 32 per cent before November 11, 34 per cent before November 18 and 40 per cent before November 25.

Tables 15 and 16 present the results of each of these criterion with the effect on harvest and average income. The effect on average income by changing the criterion is not great. Tables 17 and 18 show the effect on individual years. These tables show that in the first year the decision concerning which criterion to use effects management

Table 15. Results for Each Combine on 200 Acres with Different Criteria Concerning the Grain Moisture Content

Criterion	Date harvest started[a]			Tractable days after harvest started[b]			Acres harvested during harvest period[c]		Net cash income[d]		Management income[d]	
	1st year	2nd year	3rd year	[1st yr	2nd yr	3rd yr]	2-row	4-row	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
.28[e]	10/31	11/09	10/15	22	7	32	163	187	8466	3926	-3451	-3644
.30[e]	10/28	11/08	10/15	24	8	32	167	195	8449	8945	-3469	-3623
.32[e]	10/24	11/08	10/15	28	8	32	168	195	8213	8601	-3705	-3968
Sliding[f]	10/29	11/08	10/16	23	8	31	168	195	8577	10098	-3340	-3471

[a]First day that the moisture criterion was met and the soil was tractable.

[b]Number of days after harvest started that the land was tractable.

[c]Average of the three years.

[d]Include the $45.00 per acre cost prior to harvest. Figures are three year averages.

[e]Harvest could start when the grain moisture content fell below .28, .30, .32 respectively.

[f]Harvest could start if grain moisture content fell below .26 before October 21, .28 before October 28, .30 before November 4, .32 before November 11, .34 before November 18, .40 before November 25.

Table 16. Results for Each Combine on 500 Acres with Different Criteria Concerning the Grain Moisture Content

Criterion	Date harvest started[a]			Tractable days after harvest started[b]			Acres harvested during harvest period[c]		Net cash income[d]		Management income[d]	
	1st year	2nd year	3rd year	[1st yr	2nd yr	3rd yr]	2-row	4-row	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
.28[e]	10/31	11/09	10/15	22	7	32	152	372	15267	20686	-10150	-5383
.30[e]	10/28	11/08	10/15	24	8	32	270	395	16071	21485	-9346	-4585
.32[e]	10/24	11/08	10/15	28	8	32	287	395	16803	20942	-8614	-5128
Sliding[f]	10/29	11/08	10/16	23	8	31	260	395	15729	21779	-9688	-4290

[a]First day that the moisture criterion was met and the soil was tractable.

[b]Number of days after harvest started that the land was tractable.

[c]Average of the three years.

[d]Include the $45.00 per acre cost prior to harvest. Figures are three year averages.

[e]Harvest could start when the grain moisture content fell below .28, .30, .32 respectively.

[f]Harvest could start if grain moisture content fell -elow .26 before October 21, .28 before October 28, .30 before November 4, .32 before November 11, .34 before November 18, .40 before November 25.

Table 17. The Effect of Alternative Grain Moisture Criteria on Management Income for Each Year with a 200 Acre Corn Enterprise

Criterion	First year		Second year		Third year	
	Two-row (dol.)	Four-row (dol.)	Two-row (dol.)	Four-row (dol.)	Two-row (dol.)	Four-row (dol.)
.28[a]	5907	4924	-10664	-8811	-5596	-7045
.30[a]	5437	4341	-10249	-8169	-5596	-7045
.32[a]	4734	3318	-10252	-8178	-5596	-7045
Sliding[b]	5602	4541	-10249	-8169	-5582	-6786

[a]Harvest can start when the grain moisture content falls below .28, .30, .32 respectively.

[b]Harvest can start if grain moisture content falls below .26 before October 21, .28 before October 28, .30 before November 4, .32 before November 11, .34 before November 18, .40 before November 25.

Table 18. The Effect of Alternative Grain Moisture Criteria on Management Income for Each Year with a 500 Acre Corn Enterprise

	First year		Second year		Third year	
Criterion	Two-row (dol.)	Four-row (dol.)	Two-row (dol.)	Four-row (dol.)	Two-row (dol.)	Four-row (dol.)
.28[a]	5866	17322	-26701	-24950	-9616	-8521
.30[a]	7821	18807	-26243	-24035	-9616	-8521
.32[a]	10016	17177	-26243	-24035	-9616	-8521
Sliding[b]	7076	19679	-26243	-24035	-9901	-8015

[a]Harvest can start whenever the grain moisture content falls below .28, .30 and .32 respectively.

[b]Harvest can occur if the grain moisture content falls below .26 before October 21, .28 before October 28, .30 before November 4, .32 before November 11, .34 before November 18, .40 before November 25.

income significantly. The effect is small or nonexistant in the second and third years because the soil is not tractable on most of the days the criteria affect. Tables with harvest and average income results similar to Tables 15 and 16 are presented in Appendix Tables B. 20, B. 21 and B. 22 for 300, 400 and 1000 acres respectively.

Opportunity Cost of Labor

The value of the labor of the combine operator can come from one of two places. If the operator is a hired laborer, the value is his wage. If the farm manager operates the combine the value is his opportunity cost during that time. Five values are used for this value which is labeled the opportunity cost of labor. These values are $2.00, $3.00, $5.00, $8.00 and $12.00 per hour. $8.00 and particularly $12.00 seem very high and unrealistic; however, in certain instances where the operator had to leave other jobs, particularly fall plowing, these high rates may apply.

Tables 19 and 20 show for 200 and 500 acres respectively the hours required, the labor expense and the resulting average income for each of the five levels of opportunity cost. The effect is very straight forward with income being reduced the amount of the labor expense. The effect is nearly the same in each of the three years.

Average Temperature

Changes in the average temperature are studied by increasing or decreasing the maximum and minimum temperature each day from October 1 through December 31. Increases in average temperature reduce the grain moisture content more rapidly. Five levels of average temperature

Table 19. The Effect of the Opportunity Cost of the Combine Operator on Averages for Hours Required, Labor Expense and Income with 200 Acres

Opportunity cost per hour	Hours required[a]		Total labor expense for harvesting		Net cash income		Management income	
	2-row	4-row	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
2.00	128	70	256	141	9153	9765	-2764	-2804
3.00	128	70	383	211	9025	9694	-2892	-2875
5.00	128	70	639	352	8770	9553	-3148	-3016
8.00	128	70	1022	564	8386	9342	-3531	-3227
12.00	128	70	1532	846	7876	9060	-4041	-3511

[a] This figure is merely the hours the combine is in use.

Table 20. The Effect of the Opportunity Cost of the Combine Operator on Averages for Hours Required, Labor Expense and Income from a 500 Acre Enterprise

Opportunity cost per hour	Hours required[a]		Total labor expense for harvesting		Net cash income		Management income	
	2-row	4-row	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
2.00	330	179	659	359	16391	22086	-9026	-3983
3.00	330	179	989	538	16061	21907	-9355	-4163
5.00	330	179	1648	897	15399	21547	-10014	-4488
8.00	330	179	2637	1436	14313	21009	-11003	-5060
12.00	330	179	3955	2153	13095	20291	-12321	-5778

[a] This figure is merely the hours the combine is in use.

are used: the level that prevailed in 1966-68, that level increased by one and five degrees, and that level decreased by one and five degrees.

Table 21 and 22 contain the results of using the five selected temperatures. The higher the temperature; the greater the income. Only in the first year do changes in the average temperature have a noticeable effect on the number of tractable days after harvest began. When the average temperature was decreased five degrees, the harvest was never completed in the first and second years using a 30 per cent grain moisture criterion due to the assumption that the moisture content must fall to that level. A four degree decrease in the first year and a three or four degree decrease in the second year created the same problem. To obtain the values in Tables 21 and 22 for a decrease of five degrees, the corn is harvested on December 31 regardless of the grain moisture criteria.

Additional Rainfall

The effect of rainfall is studied by additional rainfall since a reduction in rainfall can not be made uniform for the three years. The four levels of rainfall used are the actual rainfall in 1966-68, an additional inch on October 15, an additional inch on November 1 and an additional inch on November 15. The additional rainfall affects the soil moisture, and thus the tractability. The effect will also depend on the soil moisture conditions previous to the rainfall and the amount of rainfall on the given day and several days following.

The effect of the four levels of rainfall on harvest, average drying expense and income is shown in Tables 23 and 24 for 200 and 500

Table 21. The Effect of Temperature Changes on a 200 Acre Corn Enterprise with a Two-Row and a Four-Row Combine[a]

	First date of harvest[b]			Tractable days[c]			Acres harvested[d]		Drying expense[e]		Management income[f]	
	1st year	2nd year	3rd year	1st year	2nd year	3rd year	2-row	4-row	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
Normal	10/28	11/08	10/15	24	8	32	168	195	2179	2595	-3469	-3623
+1°	10/28	11/08	10/15	24	8	32	168	195	1887	2261	-3106	-3233
+5°	10/26	11/08	10/15	26	8	32	168	195	1410	1770	-2537	-2647
-1°	10/29	11/08	10/15	23	8	32	168	195	2433	2817	-3753	-3894
-5°[g]	11/02	11/26	10/15	19[h]	5[i]	32	101	126	2950	3171	-8390	-7918

[a]The changes in temperature is the addition or subtraction of the appropriate number of degrees from the maximum and the minimum temperature for each day from October 15 - December 31.

[b]First date after the grain moisture content reaches .30 that the soil is dry.

[c]The number of days after the grain moisture content reaches .30 that the soil is such that harvest can occur.

[d]Average number of acres harvested during the harvest period for the three years.

[e]Cost to dry the corn to 15.5 per cent moisture. Figures are three year average.

[f]$45.00 per acre pre-harvest cost is subtracted out. Figures are three year averages.

[g]In years 1 and 2 harvest was completed in December with grain moisture above .30.

[h]Fourteen of the 19 days the grain moisture was above 30 per cent.

[i]Two of the 5 days the grain moisture was above 30 per cent.

Table 22. The Effect of Temperature Changes on a 500 Acre Corn Enterprise with a Two-Row and a Four-Row Combine[a]

	First date of harvest[b]			Tractable days[c]			Acres harvested[d]		Drying expense[e]		Management income[f]	
	1st year	2nd year	3rd year	1st year	2nd year	3rd year	2-row	4-row	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
Normal	10/28	11/08	10/15	24	8	32	270	395	3932	4967	-9345	-4584
+1°	10/28	11/08	10/15	24	8	32	270	395	3095	4135	-8391	-3620
+5°	10/26	11/08	10/15	26	8	32	278	393	2588	3140	-7221	-2527
-1°	10/29	11/08	10/15	23	8	32	265	395	4541	5578	-10424	-5324
-5°[g]	11/02	11/26	10/15	19[h]	5[i]	32	172	225	7098	7156	-19314	-17782

[a]The changes in temperature is the addition or subtraction of the appropriate number of degrees from the maximum and the minimum temperature for each day from October 15 - December 31.

[b]First date after the grain moisture content reaches .30 that the soil is dry.

[c]The number of days after the grain moisture content reaches .30 that the soil is such that harvest can occur.

[d]Average number of acres harvested during the harvest period for the three years.

[e]Cost to dry the corn to 15.5 per cent moisture. Figures are three year average.

[f]$45.00 per acre pre-harvest cost is subtracted out. Figures are three year averages.

[g]In years 1 and 2 harvest was completed in December with grain moisture above .30.

[h]Fourteen of the 19 days the grain moisture was above 30 per cent.

[i]Two of the 5 days the grain moisture was above 30 per cent.

Table 23. Effect of Additional Rainfall During the Harvesting Season with a 200 Acre Corn Enterprise for each Combine

	First date of harvest[a]			Tractable days[b]			Acres harvested[c]		Drying expense		Management income[d]	
	1st year	2nd year	3rd year	1st year	2nd year	3rd year	2-row	4-row	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
"Normal"[e]	10/28	11/08	10/15	24	8	32	168	194	2197	2595	-3469	-3623
+1" Oct 15	10/28	11/08	10/17	22	8	30	168	195	2096	2448	-3308	-3464
+1" Nov 1	10/28	11/08	10/15	16	8	27	166	198	1997	2460	-3356	-3498
+1" Nov 15	10/28	11/08	10/15	20	8	32	166	198	2180	2595	-3443	-3623

[a]First date after grain moisture content reaches .30 that the ground is dry.

[b]Number of days after grain moisture content reaches .30 that the soil is such that harvest can occur.

[c]Acres (3 year average) that were harvested during the harvest period.

[d]Includes the $45.00 per acre of costs incurred prior to harvest. Figures are three year averages.

[e]"Normal" rainfall is shown in the Appendix.

Table 24. Effect of Additional Rainfall During the Harvesting Season with a 500 Acre Corn Enterprise for each Combine

	First date of harvest[a]			Tractable days[b]			Acres harvested[c]		Drying expense		Management income[d]	
	1st year	2nd year	3rd year	1st year	2nd year	3rd year	2-row	4-row	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
"Normal"[e]	10/28	11/08	10/15	24	8	32	270	395	3932	4967	-9345	-4584
+1" Oct 15	10/28	11/08	10/17	22	8	30	273	395	3779	4753	-9777	-4202
+1" Nov 1	10/28	11/08	10/15	16	8	27	215	343	3519	4306	-11970	-7240
+1" Nov 15	10/28	11/08	10/15	20	8	32	253	375	3814	4790	-10339	-5729

[a]First date after grain moisture content reaches .30 that the ground is dry.

[b]Number of days after grain moisture content reaches .30 that the soil is such that harvest can occur.

[c]Acres (3 year average) that were harvested during the harvest period.

[d]Includes the $45.00 per acre of costs incurred prior to harvest. Figures are three year averages.

[e]"Normal" rainfall is shown in the Appendix.

acres respectively. The additional rainfall increased income in certain cases particularly with 200 acres, decreases income in others especially with 500 acres and had no effect in some other cases. In the cases where additional rainfall increases income, the reason is that after the rain the grain dried faster than the soil resulting in lower drying charges. When no effect is shown, either the soil is already saturated causing the additional rain to run off, or harvest has already been completed.

Price

Seven levels of prices are used. The prices prevailing in 1966-68 by weeks are used as the base. All corn is assumed to be sold the day it is harvested at the price for that week. The other six levels are the base price plus and minus one cent, five cents and ten cents. Tables 25 and 26 show for 200 and 500 acres respectively the expected relationship between changes in price and income.

Yield

Three levels of yield are used. The levels refer to the potential yield as of October 15. The base level is the potential yield for each year that is typical of the yields for 1966-68. The second and third levels are ten bushels more and ten bushels less. Tables 27 and 28 present the results from the three levels for 200 and 500 acres respectively. The results are once again as expected. One should note the much greater effect on management income with a 500 acre enterprise.

Table 25. The Consequences of a Change in Price with a 200 Acre Corn Enterprise and a Two-Row and a Four-Row Combine

	Average price of corn each year[a]			Average price received[b]		Net cash income[c]		Management income[c]	
	1st year (dol.)	2nd year (dol.)	3rd year (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
Normal	1.23	1.06	.96	1.065	1.059	8448	8946	-3469	-3623
+$.01	1.24	1.07	.97	1.075	1.069	8672	9129	-3245	-3389
+$.05	1.28	1.11	1.01	1.115	1.109	9564	10064	-2352	-2454
+$.10	1.33	1.16	1.06	1.165	1.159	10375	11234	-1236	-1284
-$.01	1.22	1.05	.95	1.055	1.049	8224	8661	-3692	-3857
-$.05	1.18	1.01	.91	1.015	1.009	7332	7726	-4585	-4793
-$.10	1.13	.96	.86	.965	.959	6215	6556	-5701	-5962

[a]Average of prevailing price on harvesting days: October 15-November 30, December 31.

[b]Average price actually received over the three years.

[c]The figures are averages of the three years.

Table 26. The Consequences of a Change in Price with a 500 Acre Corn Enterprise Using a Two-Row and a Four-Row Combine

	Average price of corn each year[a]			Average price received[b]		Net cash income[c]		Management income[c]	
	1st year (dol.)	2nd year (dol.)	3rd year (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
Normal	1.23	1.06	.96	1.082	1.073	16071	21481	-9345	-4584
+$.01	1.24	1.07	.97	1.092	1.083	16552	22033	-8885	-4037
+$.05	1.28	1.11	1.01	1.132	1.123	18475	24223	-6942	-1846
+$.10	1.33	1.16	1.06	1.182	1.173	20815	26962	-4539	893
-$.01	1.22	1.05	.95	1.072	1.063	15590	20937	-9829	-5132
-$.05	1.18	1.01	.91	1.032	1.023	13668	18747	-11749	-7323
-$.10	1.13	.96	.86	.982	.973	11265	16007	-14152	-10062

[a] Average of prevailing price on harvesting days: October 15-November 30, December 31.

[b] Average price actually received over the three years.

[c] The figures are averages of the three years.

Table 27. The Effect of Variations in Potential Yield on a 200 Acre Corn Enterprise

	Potential yield			Actual yield						Net cash income		Management income	
	1st year	2nd year	3rd year	1st year 2-row	1st year 4-row	2nd year 2-row	2nd year 4-row	3rd year 2-row	3rd year 4-row	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
-10 bu.	140	90	115	131.8	131.9	67.4	82.0	109.6	109.7	6888	7362	-5019	-5207
Normal	150	100	125	141.2	141.3	74.6	90.3	119.1	119.2	8448	8946	-3469	-3623
+10 bu.	160	110	135	150.6	150.7	81.6	99.3	128.7	128.9	10138	10572	-1922	-1998

Table 28. The Effect of Variations in Potential Yield on a 500 Acre Corn Enterprise

	Potential yield			Actual yield						Net cash income		Management income	
	1st year	2nd year	3rd year	1st year 2-row	1st year 4-row	2nd year 2-row	2nd year 4-row	3rd year 2-row	3rd year 4-row	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
-10 bu.	140	90	115	109.4	131.6	56.2	63.6	101.1	109.5	12740	17620	-12677	-8449
Normal	150	100	125	116.6	141.0	62.4	68.7	109.4	119.0	16071	21485	-9346	-4584
+10 bu.	160	110	135	123.7	150.3	68.6	75.6	117.6	128.5	19389	25405	-6029	-664

Footnotes

1. The model as developed by the task force assumed all of the corn not harvested during the harvesting season is harvested on December 31. Field losses for corn harvested December 31 are determined with the same functions used during the harvesting period.

2. Income is determined using a $960 charge for the operator's labor and $2.00 per hour for any hours in excess of 320; however, the income can easily be adjusted to reflect the opportunity cost.

3. Additional rainfall is used since an equivalent reduction in rainfall could not be made in each of the three years.

4. The $45.00 per acre charge includes:

seed	$ 4.00
fertilizer	20.00
herbicide	5.00
machinery and labor	16.00
Total	$45.00

CHAPTER V

ANALYSIS OF THE EFFECT OF THE SELECTED VARIABLES IN THE HARVESTING PERIOD

In this chapter, the results presented in the previous chapter are analyzed and interpreted so that conclusions can be reached that will enable farm managers to improve their decisions relative to the harvesting system. The nine variables are ranked as to their effect on income for several situations. These same variables are then ranked as to their effect on income from the use of the two-row and the four-row combines. From these rankings and the magnitude of the changes, conclusions can be made as to which of the selected variables create significant changes in income under specified conditions. The chapter therefore, includes an individual look at each of the nine variables to discuss that variable's impact on the harvesting system.

The changes in management income are used as the basis for the ranking of the selected variables. Since management income is the return for the farmer's management, all costs, both cash and non-cash, have been subtracted from income. If any other income figure were used, some of the costs would not be subtracted. Therefore, changes in the unincluded expenses from changes in a variable would not be reflected in the ranking of the variables.

Ranking of the Effect on Income

In order to determine the effect of changes in variables, the magnitude of change for each of the nine variables had to be established. The following nine changes are used:

1. Failure to complete harvest by December 1: 20% to 40% loss.
2. Size of Corn Enterprise: 100 acre change.
3. Hours in the working day: 2 hour change.
4. Criterion of how low grain moisture content must be: .02 change.
5. Opportunity cost: $3.00 per hour change.
6. Additional rainfall: one inch.
7. Temperature: 5% change (1).
8. Price: $.05 per bushel change.
9. Yield: 10 bushel change in the potential yield as of October 1.

Each of these changes has approximately the same probability of occurring on a given farm situation. Although the decision concerning the magnitude of the change is somewhat arbitrary, the consequences of possible inaccuracies are less serious because the effect of the changes in the variables relative to the other variables is most important. The absolute change in each variable is of a lesser importance since each set of changes would produce a different set of absolute changes; however, each equivalent set of changes should have a similar relative effect on the variables.

In order to study more thoroughly the effect of the size of the enterprise, rankings were made for a 200 acre and a 500 acre corn enterprise. For the 200 acre enterprise the magnitude of the effect of the change in size is determined by changing from a 200 to a 300 acre enterprise. For the rankings for a 500 acre enterprise, a change from 400 to 500 acres is used. Major emphasis is placed on the effect of changes in the size of enterprise since the relevant range of sizes of enterprise is much larger than the relevant range for the other variables. Also, farm managers are especially concerned with the effect of changes in the size of their enterprise.

The first situation used for ranking is the three individual years. Before presenting the rankings for the years, the conditions prevailing in each of the three years should be reviewed. The first year is characterized by excellent yields, high prices and ample harvest time. In the second year the farm manager encounters low yields, prices slightly below average and disastrous harvesting conditions with very high grain moisture content and extremely wet field conditions. In year three the yield is average, conditions during the harvest period are excellent but prices are very low. The first year, therefore, is highly profitable. The third year can be profitable with a favorable set of variables but seldom financially disastrous. However, the second year is financially disastrous especially as size increases. Table 29 illustrates the important characteristics of the three years and presents management income using the base values specified in the previous chapter. The conditions prevailing in this three year period appear to be somewhat less favorable than average primarily because of the conditions in the second year.

Tables 30 and 31 rank for 200 and 500 acres respectively the effect of the given changes in the nine variables. Appendix Tables

Table 29. A Summary of the Situation Existing in the Three Harvesting Periods Studied

	Unit	First year	Second year	Third year
Maximum yield as of September 30	Bu.	150	100	125
Grain moisture on October 15	Per Cent	36.0	40.3	26.9
Average price	Dol.	1.23	1.06	0.96
Harvest conditions		Good	Very poor	Excellent
Management income[a]				
200 acres 2-row	Dol.	5,424	-10,351	-5,939
200 acres 4-row	Dol.	4,326	-8,305	-7,503
500 acres 2-row	Dol.	7,808	-26,345	-9,959
500 acres 4-row	Dol.	18,790	-24,171	-8,984

[a]Using base values.

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Table 30. The Rank of the Magnitude of the Effect of the Given Changes in the Nine Selected Variables on Management Income with a 200 Acre Enterprise for a Two-Row and a Four-Row Combine

Variable	Rank[a]							
	1st year		2nd year		3rd year		Average[b]	
	2-row	4-row	2-row	4-row	2-row	4-row	2-row	4-row
Size of enterprise	1	1	1	1	5	4	6	4
Temperature	2	3	3	2	6	2	2	2
Price	3	2	5	3	1	1	1	1
Yield	4	4	6	4	2	3	3	3
Grain moisture	5	5	8	6	8	6	5	6
Opportunity cost	6	6	7	8	3	5	8	5
Hours	7	7	4	5	4	7	7	7
Rainfall	8	8	9	9	7	8	9	8
Loss	9	9	2	7	9	9	4	9

[a]The rank is based on the absolute value of the change in management income.

[b]In summing the changes in the three years the sign of the changes is included. Increases in one year may offset decreases in another.

Table 31

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Table 31. The Rank of the Magnitude of the Effect of the Given Changes in the Nine Selected Variables on Management Income with a 500 Acre Enterprise for a Two-Row and a Four-Row Combine

Variable	Rank[a]							
	1st year		2nd year		3rd year		Average[b]	
	2-row	4-row	2-row	4-row	2-row	4-row	2-row	4-row
Size of enterprise	9	1	2	1	1	7	2	8
Temperature	2	3	3	3	8	4	5	2
Price	5	4	4	4	2	1	4	1
Yield	7	5	5	6	5	2	6	3
Grain moisture	6	8	8	8	9	8	9	7
Opportunity cost	8	7	6	7	6	6	8	6
Hours	3	6	7	5	3	3	3	9
Rainfall	4	2	9	9	7	5	7	5
Loss	1	9	1	2	4	9	1	4

[a]The rank is based on the absolute value of the change in management income.

[b]In summing the changes for the three years the sign of the changes is included.

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C. 1 and C. 2 present the dollar value of the change for 200 and 500 acres while Appendix Tables C. 3 and C. 4 provide the ranking in descending order of importance for each year and the average of the three years. The rank is based upon the absolute value of the change with the direction of the change not considered. When the average effect is calculated, the sign of the value for each individual year is considered to calculate the average, and then the rank is determined from the absolute value of the average. For several variables--size of enterprise, hours, grain moisture and additional rainfall--the direction of the change depends upon the year. The size of enterprise where its importance is considerably less in the average than in the individual years is an excellent example of the offsetting directions of the change.

The rankings made by years fail to present any consistent pattern. The variables size of enterprise, temperature, price and yield appear to have the greatest effect. The variables loss and hours have a large effect in some years especially with 500 acres. With a two-row machine the variables loss and hours command more importance. Although the above generalizations can be reached, a more distinct pattern must be found.

Much of the fluctuation in the rankings can be explained by the success or failure to complete harvest by December 1. The variables size of enterprise, hours, grain moisture and rainfall create opposite effects on income with and without completion of harvest during the harvest period. When the harvest is easily completed, increased size increases management income, however, when harvest is not completed

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during the harvest period the increased acres are harvested with the 40 per cent loss and thus creates a decrease in income. When harvest is completed easily, increased hours, increased maximum grain moisture and lack of rainfall produce less management income since these changes enable harvest to be completed earlier creating increased drying and hauling charges. When harvest is not completed during the harvesting season these same changes increase income by decreasing the loss from failure to complete harvest. Table 32 describes the effect of changes in each of the variables with and without completion of harvest during the harvesting period.

Tables 33 and 34 present for 200 and 500 acre enterprises respectively the rankings and the percentage change for each variable with and without completion of harvest during the harvesting period. The rankings are made using absolute values of the average changes for each variable. The percentage is calculated by dividing the given change by the average management income using base values and the given size of enterprise and size of combine. For the 200 acre enterprise the harvest is completed within the harvesting season in the first and third years using either combine. Harvest is not completed in the second year with either combine due to the adverse weather conditions. With a 500 acre enterprise the two-row never completes harvest during the harvesting period, whereas the four-row completes harvest in the first and third years. Appendix Tables C. 5 and C. 6 contain the actual values for the changes for a 200 and a 500 acre enterprise respectively. The ranking for completion and non-completion in decreasing order of importance is contained in Appendix Tables C. 7 and C. 8 for the two enterprise sizes.

Table 3

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Table 32. The Direction of the Change in Management Income from Changing the Variables with and without Completion of Harvest During the Harvesting Period

Variable	Completion	No Completion
Size of enterprise	Increased income with increased size	Decreased income with increased size
Temperature	Small increases with higher temperature	Large increases with higher temperature
Price	Increased income with price increases	Increased income with price increases
Yield	Increased income with yield increases	Increased income with yield increases
Grain moisture	Decreased income with increased maximum[a]	Increased income with increased maximum[a]
Opportunity cost	Lower income with increased labor cost	Lower income with increased labor cost
Hours	Lower income with increased hours	Higher income with increased hours
Rainfall	Increased income with additional rainfall	Lower income with additional rainfall
Loss	No effect	Lower income with increased loss

[a]Increased maximum means an earlier harvest.

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Table 33. The Ranking of the Variables and the Percentage Change in Management Income when Harvest is and is not Completed for a 200 Acre Enterprise for a Two-Row and a Four-Row Combine[a]

Variable	2-row				4-row			
	Completed		Not Completed		Completed		Not Completed	
	Rank[b]	% Change[c]	Rank[b]	% Change[c]	Rank[b]	% Change[c]	Rank[b]	% Change[c]
Size of enterprise	1	60.0	1	146.8	1	49.0	1	141.7
Temperature	3	25.1	3	26.9	3	22.8	2	30.0
Price	2	35.9	5	20.6	2	30.3	3	23.6
Yield	4	23.5	6	17.2	4	21.5	4	20.0
Grain moisture	7	5.3	8	5.8	5	10.5	6	8.5
Opportunity cost	5	10.5	7	13.7	6	5.5	8	5.5
Hours	6	7.2	4	24.2	7	4.5	5	11.5
Rainfall	8	4.2	9	0.0	8	2.5	9	-0-
Loss	9	0.0	2	43.1	9	-0-	7	6.8

[a]Completion of harvest means completed by December 1.

[b]The rank is based on the absolute value of the change in management income.

[c]The percentage change in each variable is based upon management income using the base values 2-row = \$-3622, 4-row = -\$3827.

Table 34. The Ranking of the Variables and the Percentage Change in Management Income when Harvest is and is not Completed for a 500 Acre Enterprise for a Two-Row and a Four-Row Combine[a]

Variable	2-row[b] Not completed		4-row Completed		4-row Not completed	
	Rank[c]	% Change[d]	Rank[c]	% Change[d]	Rank[c]	% Change[d]
Size of enterprise	2	34.9	2	51.3	1	112.8
Temperature	5	22.4	4	42.6	4	43.6
Price	4	25.3	1	67.9	5	35.9
Yield	6	17.5	3	45.2	7	31.1
Grain moisture	9	8.1	8	0.7	9	9.6
Opportunity cost	8	10.4	6	10.1	8	11.4
Hours	3	27.2	5	16.9	6	35.5
Rainfall	7	14.2	7	9.1	3	43.7
Loss	1	50.9	9	-0-	2	107.1

[a]Completion of harvest means completed by December 1.

[b]The harvest was not completed using the two-row combine in any of the three years.

[c]The rank is based on the absolute value of the change in management income.

[d]The percentage change in each variable is based upon management income using the base values 2-row = $-9499, 4-row = $-4788.

When the harvest is completed before December 1, the size of enterprise, price, temperature and yield have major effects on management incomes. For the given changes, each of the four variables affected income by more than 20 per cent under each situation where harvesting is completed. None of the other variables consistently affect income as much as 10 per cent. The variable changes which increase the speed of harvest--increased hours in the work day, higher maximum grain moisture and lack of additional rainfall--create a minor decrease in income. The opportunity cost of labor has only a small effect since the labor expense for operating the combine is not a major expense.

When harvest is not completed during the harvest season, the rankings have less pattern than for completion of harvest but more than for the individual years. The reduction in the degree of similarity is created because each situation has a different proportion of the corn still in the field at the end of the harvesting period. Most farm managers seldom face this problem of not being able to complete harvest; however, when they do, they are faced with a situation where at least six of the nine variables have a large effect on income. The four variables that are important when harvest is completed--size of enterprise, temperature, price and yield are still very important. The size of enterprise and average temperatures have a greater effect while price and yield have a slightly diminished effect. The variables loss and hours now consistently have a large effect on income. Only with a four-row combine and a 200 acre enterprise was the effect of loss less than 40 per cent or the effect of hours less than 20 per cent. The effect was much less with the four-row combine on a 200 acre

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enterprise because only 16 acres were left unharvested. Changes in the maximum grain moisture and rainfall seldom had a large effect because on the days when the changes would have had an effect, the soil was usually not tractable. The opportunity cost of labor was the only variable that never showed a potentially large effect. These conclusions would indicate that when a farm manager reaches a situation either because of bad weather or poor management where he may not complete harvest on time, he will have to consider an increased number of variables.

Effect of Changes in Variables on the Choice of a Combine

Changes in the nine variables being studied can also affect the choice of a two-row or a four-row combine. Using the same changes as in the previous section, the effect of the nine variables on the relative income position created by the use of each machine is studied. For each variable the change in difference in management income received from the two machines (income using a four-row combine minus income using a two-row machine) is calculated. Appendix Tables C. 9 and C. 10 present for 200 and 500 acres respectively the actual change in the difference between the two machines for each of the three years and the average of the three years. Appendix C. 11 then shows the corresponding rankings in order of decreasing importance for 200 and 500 acre enterprises in each of the three years and the average of the three years.

Once again the yearly rankings are scrambled because in some years harvest is completed during the harvest season while in others it is not completed until December 31. The values for the individual years indicate that the variables size of enterprise, loss and hours in the work day are of major importance when a choice is to be made between a two-row and a four-row combine. Under certain conditions the grain moisture criterion and rainfall appear to be important variables.

In comparing the two machines relative to completion of harvest, three categories are needed: one in which both combines complete the harvest during the harvest season, one in which the two-row does not finish but the four-row does and one in which neither combine completes the harvest. The first and third years with 200 acres fill the first category. The first and third years with a 500 acre enterprise occupy the second category while the second year for both enterprise sizes is contained in the third category. Since the years and acreages differ, the actual values are highly questionable; however, the relative values and the rankings from the changing variables provide valuable insight into the effect of these variables on the choice of machines. Appendix Table C. 12 lists the actual values ranked in descending order for each of the three categories. Table 35 ranks each of the nine variables and shows a percentage change in income for each of the three categories. Since no logical base was available, the percentage change is based upon an average of the management income from the two machines used on the two enterprise sizes (-$5,434).

A quick glance at the first part of Table 35 illustrates to the reader that changing the variables under study has little effect on the relative income position of the machine when both combines complete harvest during the harvest period. Although the increase is small,

Table 35. The Ranking of the Variables and the Percentage Change in Management as to the Effect on the Choice between a Two-Row and a Four-Row Combine

	Both Complete		4-row Complete		Neither Complete	
	Rank	% Change[a]	Rank	% Change[a]	Rank	% Change[a]
Size of enterprise	1	5.6	1	87.9	8	0.1
Temperature	6	0.4	9	1.8	7	1.7
Price	8	-0-	7	7.8	5	2.9
Yield	5	0.5	8	6.7	6	2.2
Grain moisture	3	2.0	5	16.6	4	3.1
Opportunity cost	2	3.1	6	8.4	2	5.6
Hours	4	1.3	2	78.4	3	3.6
Rainfall	7	0.1	4	22.3	9	-0-
Loss	8	-0-	3	77.1	1	24.0

[a]The percentage change is the change in the difference in management income between the two combines divided by a base which is the average income from the two combines and the two sizes of enterprise. Base = -$5,434.

the relative income from the four-row increases as the size of the enterprise increases. In addition to this relative increase, the value of the four-row increases with increasing size since the probability of the two-row failing to complete harvest increases.

When only the four-row combine completes harvest during the harvest period, five variables provide a major influence on the relative income position of the two combines. These five variables in decreasing order of importance are: Size (87.9 per cent), hours (78.4 per cent), loss (77.1 per cent), rainfall (22.3) and grain moisture (16.6 per cent). As size increases, the four-row quickly becomes more profitable since it is harvesting the additional acres during the harvesting period while the two-row is not. Increases in the loss on those acres not harvested during the harvesting season further increases the relative income position of the four-row. The other three variables of major importance affect the amount of harvesting time available. Decreases in the work day, decreases in the maximum grain moisture and additional rainfall shorten harvesting time and thus improve the relative income position of the four-row combine. Increasing labor costs, prices and yield all provide minor increases in the relative income position of the four-row combine.

When neither combine completes harvest, the only variable showing a major effect is the loss (24.0 per cent). Some or all of the variables showing major effects in the previous category would probably have greater effects under different conditions. Only the second year fits this category so the figures have limited scope. In this situation of failure to complete harvest, the real question would almost certainly be which combine would minimize losses. The answer invariably would be the four-row as it would harvest more acres before the end of the harvest period.

From the above analysis some conclusions can be reached concerning when each of the combines would be more profitable. When completion of harvest is a near certainty with either machine, the two-row is more profitable since its ownership costs for depreciation, interest, housing and insurance are $671.00 less than for the four-row and variable cost are very similar. The farm manager should keep in mind that the effect of increasing size by 100 acres when only the four-row completes harvest during the harvesting season improved by nearly $5,000.00 the relative income position of the four-row. Based upon the magnitudes of these two values, the farm manager would appear to be smart to choose the four-row whenever the probability of the two-row not completing harvest became very large. In making a decision of this type, a farm manager must estimate values for the above figures based on his own operation.

An Analysis of Each Variable

In this section each of the nine variables is analyzed individually. Particular attention will be directed to those variables the farm manager can control; size, hours and grain moisture criterion. A decision-making rule to determine the optimum value for each of these variables is sought. The variables are discussed in decreasing order of importance when harvest is completed during the harvesting period.

Size of the Enterprise

This variable has by far the greatest effect on a harvesting system. The size of the enterprise must be determined long before the harvesting season begins. Not only must the corn be planted but investment decisions concerning the combine and other machinery must be made.

Ownership costs including depreciation, interest, housing and insurance are very high for harvesting equipment. These costs average $2,013 and $2,684 for the two-row and four-row combines respectively using the coefficients in the model. To maximize profits these costs must be spread over as many acres as possible. As is illustrated in Table 10, page 63, machinery expenses for the four-row were $3,654 for 200 acres and $4,471 for 500 acres. On a per acre basis this is $18.27 and $8.94 per acre for 200 and 500 acres respectively.

On the other hand, the ranking of the effect of changes in variables illustrated that if harvest is not completed in the harvest season, large losses would result from increases in size. These losses amounted to approximately $5,000 a year. Table 36 presents the gain from increasing acreage when harvest is completed and the loss from increasing acreage when harvest is not completed before December 31 for the three years studied.

Table 36. The Effect of Increasing the Size of the Enterprise 100 Acres when Harvest is and is not Completed[a]

Machine	Completed	Not completed
2-row	gain $2,176.00	loss $4,316.00
4-row	gain $2,166.00	loss $5,412.00

[a]All other variables given values used initially.

From the above discussion the conclusion can be drawn that given constant values for other variables, the size of the corn enterprise for harvesting purposes must be a function of the expected gain from increasing acreage when harvest is completed during the harvest season, the expected loss from acreage increases when harvest is not completed and the estimated probability of completing harvest. Since the loss from failure to complete harvest depends upon the number of acres not harvested, an accurate value would require analysis of many years and a probability distribution for the number of acres not harvested. With this figure and a more accurate gain figure, the profit maximizing enterprise size can be determined. The enterprise size should be increased until the probability of not completing harvest equals $(\frac{\text{gain}}{\text{gain + loss}})$. A farm manager who places increased value on reducing risk and a stable income would reach his optimum with a smaller probability of not completing harvest and therefore a smaller acreage. Conversely, a manager wishing to gamble would increase his size above the profit maximizing acreage. The reader must keep in mind that this optimum acreage only applies to harvest, and the actual acreage may be reduced by bottlenecks at planting time.

The fact that most farm managers begin harvest on about the same date each year would indicate that they are using a decision-making rule consistent with this conclusion. The manager's decision rule is certainly less formalized and precise; however, the above calculation would be made ex poste whereas the farm manager must make his decision ex ante.

Price

As any farm manager would say, the price of the corn being sold is an extremely important variable. When the harvest is completed during the harvesting period, the importance of price is second only to size. The magnitude of the effect of price is almost identical when harvest is and is not completed. Its rank, however, is much lower when harvest is not completed because of the increased effect of the variables affecting the duration of the harvesting period.

As the size of the enterprise increases, the price assumes a greater role (assuming perfect competition). With very large enterprises economic survival may depend on accurate price prediction. For the four-row combine a $.20 price change altered management income $4678.00 for 200 acres and $10,955.00 for 500 acres.

The expected price will affect nearly every decision the farm manager makes. Increases in price are going to increase the profit maximizing size of enterprise by increasing the amount of gain when harvest is completed and decreasing the loss when harvest is not completed during the harvest season. The price has a definite although relatively minor effect on the choice of a combine as increases in price increase the relative profitability of the four-row combine.

Temperature

Changes in the average temperature result somewhat surprisingly in large changes in income. These income changes occur because increases in average temperature decrease the grain moisture content which diminishes drying and hauling charges with a resulting increase in income. This effect has dramatic and unexpected results when the temperature is decreased in the corn simulation model. With a 5 degree decrease the grain moisture in the first and second years failed to fall below 30 per cent long enough for harvest to be completed. By allowing harvest to occur above 30 per cent after the harvest season, harvest did occur; however, income from 500 acres with a four-row combine is $28,599.00 and $7,073.00 for the first and second years respectively (2).

Since the effect of temperature appears to be greater when harvest is not completed prior to December 1. Although temperature changes have very little effect on the choice of a combine in the years being studied, the potential effect is great. Anytime that the temperature affects the length of harvest and the harvest is not completed in the harvest season, a large effect on the choice of a combine could result.

Yield

The same conclusions that were reached for the effect of changes in the price can be drawn for the effect of changes in yield. This change refers to changes in the potential yield as of October 15 rather than actual changes. This variable also has a greater effect when harvest is completed since more of the additional bushels are harvested or more of a reduction occurs. Furthermore, the effect is greater as the size of the enterprise increases and yield increases favor the larger four-row combine.

Opportunity Cost

Changes in the opportunity cost of the combine operator have the most consistent effect on income. This effect is consistently relatively minor. Increases in this charge decrease income while decreases increase income. Also, increased labor charges are favorable to the choice of the larger four-row combine since harvest is completed more quickly.

This minor effect of labor charges is largely a result of the limited scope of this analysis. First, only the harvesting system is being studied. This restriction reduces the labor used greatly. Furthermore, only the combine operator's time is counted. The transporattion and storage of the harvested corn is given a specific, unrelated change. Thus, the effect of the labor costs are greatly reduced in this model.

Hours

The effect of changes in the number of hours in the working day is quite small when the harvest is completed easily. Even when the harvest is not completed prior to the end of the harvest season, changes in the length of the work day are the easiest way of increasing harvesting time. The analysis of how to determine the maximum length of the working day must be divided into two parts. The first part of the analysis involves conditions where a set length for the working days must be determined. The second part involves situations where the length can be varied.

For both analysis the other variables are assumed to be constant. The length of the harvesting seasons including the date or a decision-rule to determine the date for commencing harvest. In both parts of the analysis increased hours decrease income when the harvest is completed easily since drying and hauling charges are increased and increase income when harvest is not completed since a larger acreage is completed. Table 37 illustrates this gain or loss.

Table 37. Gain or Loss in Income Due to an Increase of Two Hours in the Length of the Work Day

Machine	Completed	Not Completed
2-row	loss of $262.00	gain of $1728.00
4-row	loss of $490.00	gain of $1069.00

When a constant length of the work day must be determined, this length will depend upon the loss from increasing the work day when harvest is completed easily, the gain from increasing the length when harvest is not completed before loss results and the probability of completing the harvest. If increasing the length of the work day results in increased per hour costs, the gain and loss figures must be adjusted accordingly. As with the size of the enterprise, accurate values for the gain and the loss could be calculated. The length of the work day should be increased until the probability of completing harvest is reduced to equal $(\frac{\text{gain}}{\text{gain + loss}})$. A risk averter would work longer hours while a risk taker would reduce his work day.

In the case where the length of the work day can be varied, the same variables will be considered; however, these variables will be changing and will be evaluated daily or periodically. Thus, if harvesting is going very well, the probability of completing harvest will increase and the length of the work day decreased. On the other hand, if rain or repairs delay the harvest, the length of the day can be increased to maximize profit.

Once again the farm manager from his ex ante position will be unlikely to be as precise as the preceeding examples. There is little doubt, however, that this type of analysis does occur. The farm manager would be most concerned with the probability of completing harvest.

Grain Moisture

The question of when should the harvest commence is important and difficult to answer. In the simulator this decision was a function of the grain moisture content alone. Of course harvest could not actually begin until the first tractable day after this criterion was met. This criterion did not have a major effect on income; however, this small effect was largely due to the changes used and the rainfall conditions. The date at which harvest starts is, however, a major determinant of income especially when harvest is not completed.

Once again this variable has opposite effects depending upon whether harvest is completed during the harvesting season. As Table 38 illustrates, increasing the maximum grain moisture during harvest decreases income when harvest is completed and increases income when loss results due to failure to complete harvest.

Table 38. Effect of an Increase in the Maximum Allowable Grain Moisture During Harvest

Machine	Completed	Not Completed
2-row	loss of $191.00	gain of $488.00
4-row	loss of $220.00	gain of $392.00

Once again the maximum profit will be a function of loss when harvest is completed, the gain when it is not completed. Using the same method used previously, profit will be maximized when the probability of not completing harvest equals $(\frac{\text{gain}}{\text{gain + loss}})$.

Rather than using the above calculations, a criterion could be developed using the harvester size and the size of the corn enterprise to determine the starting date. With this criterion the grain moisture content would have no influence on the starting date. On the other hand, with the previous method the gains and losses were partially determined by the grain moisture content.

Rainfall

The effect of additional rainfall is very inconsistent because the effect depends upon the soil moisture and rainfall conditions when the additional rainfall occurs. When harvest is completed, additional rainfall has very little effect especially since the rainfall has little affect on the moisture content when harvest occurs. When harvest is not completed during the harvesting period, the significance of additional rainfall depends upon the effect of the rain on the harvesting time available. Any reduction in this time decreases income. In general additional rainfall increases the relative income position of the larger four-row combine.

Loss

As soon as failure to complete the harvest during the harvesting period occurs, the size of the resulting loss becomes important. With anything more than a few acres this loss has an important effect on the income. A function approaching real world conditions must have the percentage of loss increasing as the acreage not harvested increases. No satisfactory function has been found.

Footnotes

1. 5° increase was used because the decrease had a very large effect since the grain moisture content remained above the minimum.

2. These figures were not used in the ranking of variables since there magnitude resulted largely from an unrelated assumption of the model.

CHAPTER VI

RESULTS FROM THE LONG-RUN REPLACEMENT ROUTINE

In the previous two chapters the individual harvesting period was analyzed. The analysis now turns to a longer period of several years so that optimum machinery replacement can be considered. In the first part of this chapter the variables to be studied relative to their effect on optimum replacement are specified and the results from using different values for each of these variables are specified. These results are needed to determine the effect of the selected variables on the long-run replacement decision. The second and final part of this chapter specifies the optimum long-run replacement policy for the combines used in the corn simulator.

Long-Run Results

The effect of the variables chosen on long-run replacement decisions is studied using the dynamic programming replacement model discussed in Chapter III. The effect of the variables on the optimum replacement period and on the minimum cost level is presented in this section. The following seven variables are studied:

1. The source of the cost data.
2. The shape of the repair cost function given total repair cost.
3. The number of hours the machine is used.

4. Level of machinery management as reflected in repair costs.

5. Rate of obsolescence.

6. Increasing cost of the new machine.

7. The interest rate.

The procedure used to study each of these variables is to determine, for each of several values, the repair costs for the present machine for one additional year and the cost of trading the present machine for a new machine plus the repair costs for the new machine for the first year. These calculations are made yearly for the machine when it is one through seven years old. The optimum time to replace the machine is determined for six different interest rates. The interest rates are 0.0, 5.0, 7.5, 10.0, 12.5, and 20.0 per cent. The two-row combine used in the corn harvest simulator is used throughout.

The results from using the selected values for the variables are presented for a specified interest rate as "keep x years" where x can be from one to seven. This result means that to minimize cost at the specified interest rate, the new two-row combine (initial cost = $12,000) should be kept x years and then traded for another new combine. If the interest rate is zero, the average yearly cost using the optimum replacement policy is presented. When the interest rate is greater than zero, the discounted present value of the infinite cost stream commencing with and including the year in which a new combine is acquired by trade is presented as the cost figure. This figure assumes the optimal replacement policy is followed. The cost for keeping and trading in each of the seven years and the optimum policy for each interest rate with the corresponding minimum cost are presented in Appendix D for the general case with each set of data. Similar tables for all sets of variables are on file with the Department of Agricultural Economics, Michigan State University.

In the following pages each of the variables will be discussed separately with the results presented. Unless specifically indicated otherwise, the cost of keeping the used machine is only repair costs, and the cost to trade is only the cost of the new combine minus the trade-in value of the used combine plus the first year repair cost for the new machine. Two hundred hours of use is used as a base.

Repair Function

Three sources are used to derive two sets of data. The first data set uses a repair cost function derived by Armstrong (1) and a trade-in value function derived by Peacock and Brake (2). The second set is developed by Bowers (3). Table 39 presents the cost of keeping and trading a combine used 200 hours per year using the two sets of data. There is a very striking difference between the cost of keeping the used machine with the cost being much lower with the Bowers data. The cost to trade increases more rapidly with the Bowers data because he has the value of the used machine dropping more rapidly.

The resulting optimum replacement policy and its cost are presented in Table 40. The optimum policy requires the manager to use the machine longer using the Armstrong data. Also the cost is less. Note that the optimum policy depends on the interest rate with the Bowers data. Higher interest rates result in keeping the machine longer since the large "trade" cost is delayed and thus reduced further by discounting for an additional year. The higher the interest rate

Table 39. The Cost of Keeping and Trading the Two-Row Combine Used 200 Hours per Year with the Two Sets of Data

Age of Machine	Cost to Keep[a]		Cost to Trade	
	Armstrong (dol.)	Bowers (dol.)	Armstrong (dol.)	Bowers (dol.)
1	734	228	5862	5244
2	899	480	6306	5952
3	1158	816	6750	6600
4	1473	1248	7194	7176
5	1806	1784	7638	7680
6	2119	2376	8082	8148
7	2374	3072	8526	8556

[a]Cost to keep is the expected repair cost for the following year.

[b]Cost to keep is $12,000 minus the trade-in value of the given used machine plus the repair cost for the first year which is $710 for the Armstrong data and $60 for the Bowers data.

Table 40. The Optimum Replacement Period and Its Cost for Each Set of Data for a Two-Row Combine Used 200 Hours

	Armstrong	Bowers
Optimum decision	Keep 6 years for 0 and 5% interest Keep 7 years for $\geq$ 7.5% interest	Keep 5 years for 0 and 5% interest Keep 6 years for > 5% interest
Yearly cost with no interest	$2359	$2090
Discounted present value with 7.5% interest	$36,886	$32,978

the greater the discounting and thus the greater the savings from delayed expenditures.

The Shape of the Repair Cost Function

The shape of the repair cost function given a constant total repair cost affects the optimum replacement decision. For this study the total repair cost for years two through seven using Armstrong's function is $10,560. The first year is not included so that the cost of trading remains unchanging. Several shapes are used besides the normal one given by Armstrong's function. The first shape is to spread the repair cost uniformly over the six years for an average cost of $1761. For the second shape a steadily increasing function is used with each year being the same amount greater than the previous year. The remaining shapes all use the exponential probability density function with different λ's. The procedure used in determining the shape of the function is to determine the probability of each of the intervals (0, 1), (1, 2) ..., (5,6) for the given λ. These six probabilities are then adjusted so they equal one. Then, since the exponential probability density slopes in the opposite direction of the desired slope, the order of the six probabilities is inverted, and the probability represents the proportion of the total repair cost ($10,560) in that year. For example, the adjusted probability of being between 5 and 6 equals the proportion of the total repair cost in the first of the six years which represents the repair costs for the second year for the machine. The values of λ used are .2, .3, .4, .5, and 1.0.

Figures 14-21 show the distribution of the eight functions along with the optimum policy and its cost. Table 41 summarizes the optimal replacement periods. The reader should note the lack of any relationship between the length of time the combine is kept and the average cost of the optimum replacement policy. The machine is kept for seven years with a uniform cost structure because the replacement model as presently developed only allows a machine to be kept seven years. The combine would be kept forever if the uniform cost were allowed to continue.

Number of Hours of Machine Use

The effect of the number of hours the combine is used depends on the set of data used. Both sets mentioned previously are studied. The first set using the Armstrong and Peacock-Brake data showed no effect on the optimum replacement pattern by changing hours of use. The reason for the lack of change is that an increase in the hours used increases repair costs in all years an identical amount. The optimum replacement pattern and the average yearly cost without discounting are shown in Table 42 using this data for 100, 200, 300, and 400 hours of use. The "keep" cost for this data includes $360 (3 per cent of the new cost) for each year of age to cover obsolescence costs. The optimum replacement policy is to keep the combine four years for all interest rates.

The second set of data from Bowers shows significant change in the optimum policy with different hours of use. The optimum policy and the average yearly cost are shown for 100, 200, and 300 hours of use

Optimal Policy	Average Yearly Cost: $2,339
Keep 6 years for 0 and 5% interest	Discounted Present Value (7.5%): $36,886
Keep 7 years for $\geq$ 7.5% interest	

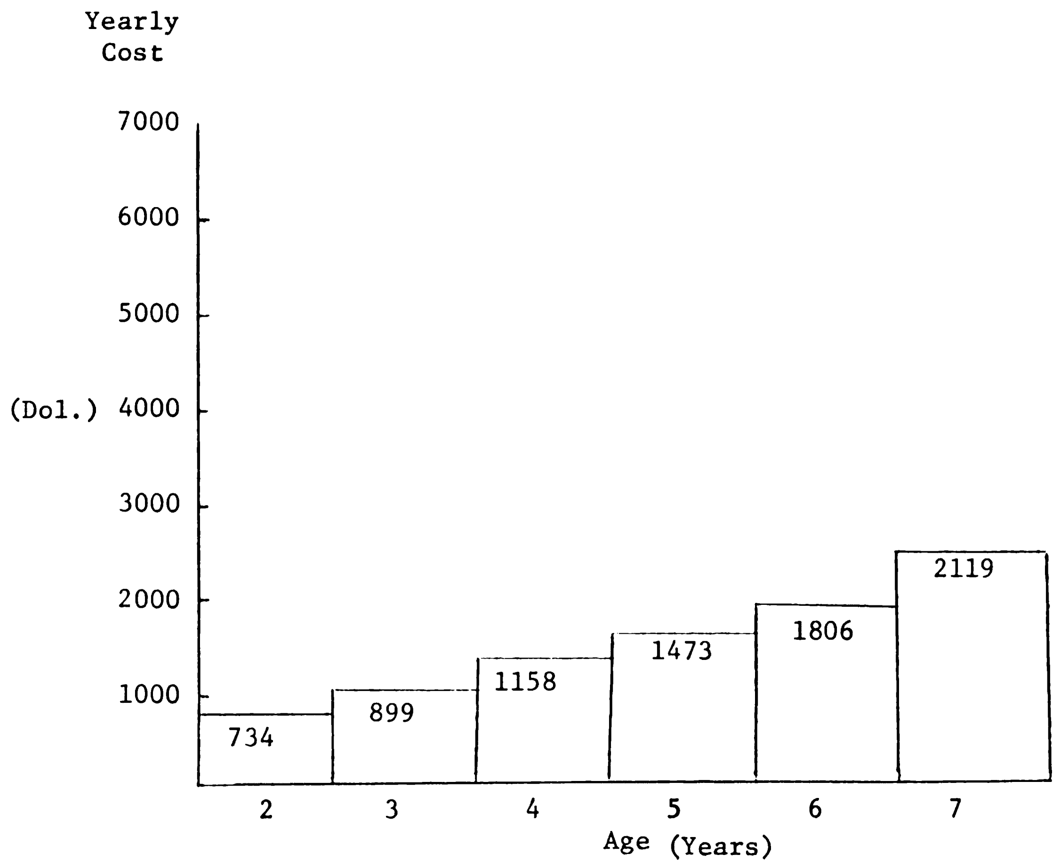

Figure 14. The Distribution of the $10,560 of Total Repair Costs Through Years Two Through Seven Using Armstrong's Function

Optimum Policy

Keep 7 years

Average Yearly Cost: $1,761

Discounted Present Value (7.5%): $42,266

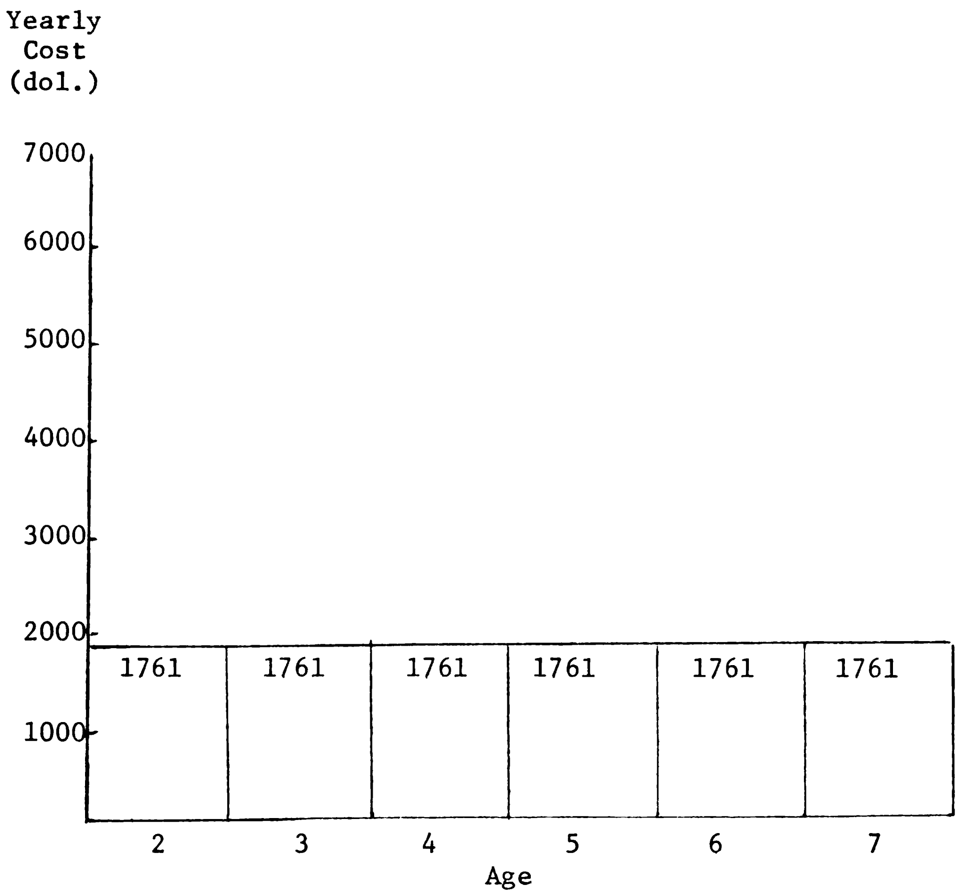

Figure 15. The Distribution of the $10,560 of Total Repair Costs for Years Two Through Seven for a Two-Row Combine with the Costs Spread Uniformly

Optimum Policy	Average Yearly Cost: $2,533
Keep 5 years for ≥ 12.5% interest	Discounted Present Value (7.5%): $38,546
Keep 6 years for 20% interest	

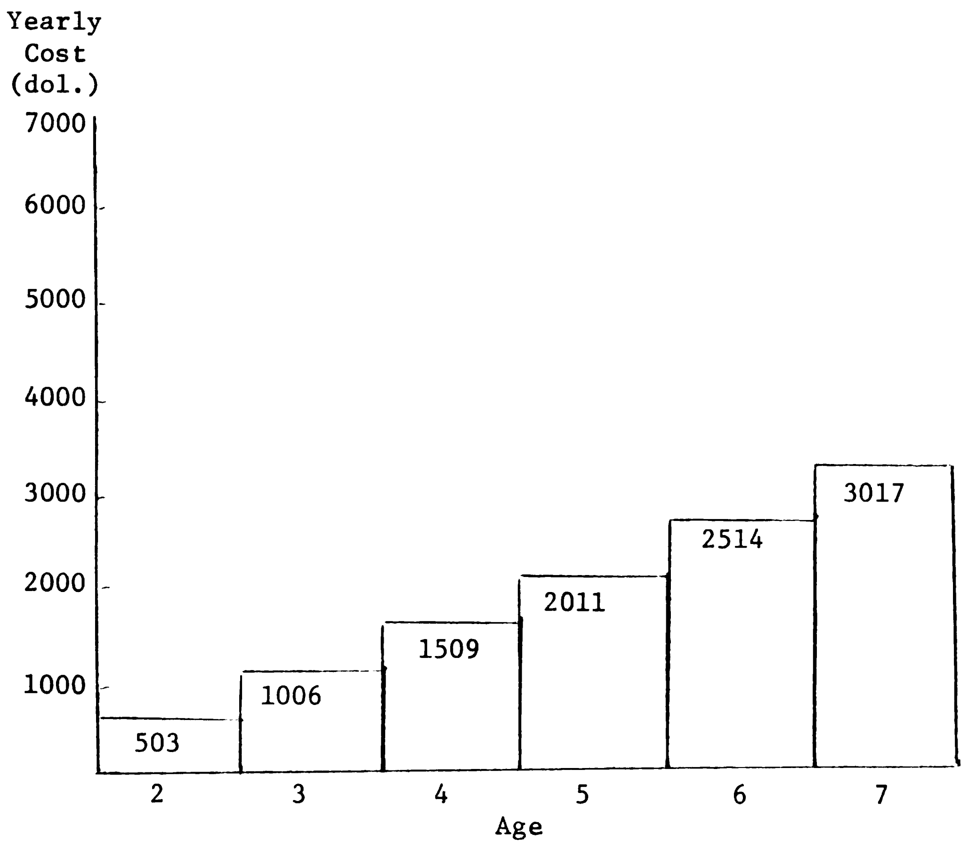

Figure 16. The Distribution of the $10,560 of Total Repair Costs for Years Two Through Seven for a Two-Row Combine with a Steadily Increasing Function

Optimum Policy

No interest
Keep 5 years

Interest ≥ 12.5%
Keep 6 years

Interest 20%
Keep 7 years

Average Yearly
Cost: $2,645

Discounted Present
Value (7.5%):
$40,441

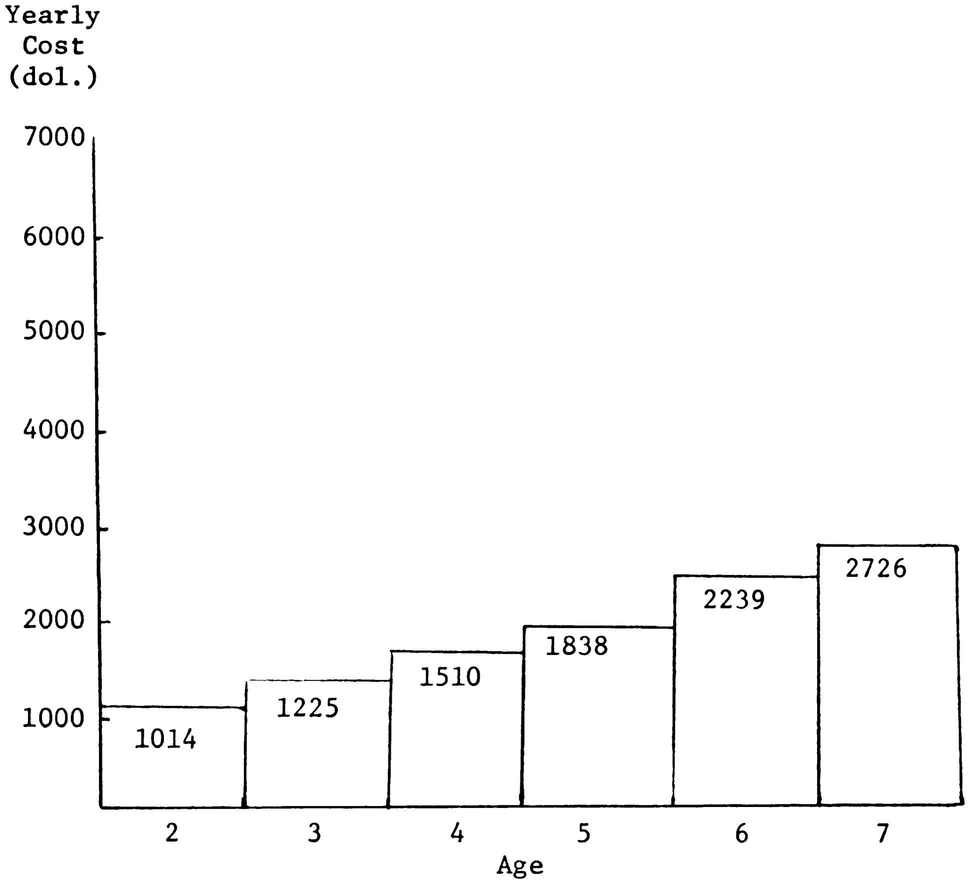

Figure 17. The Distribution of the $10,560 of Total Repair Costs for Years Two Through Seven for a Two-Row Combine with a 1-Exponential (λ = .2) Distribution

Optimum Policy	Average Yearly Cost: $2,497
Interest (≥ 12.5%) Keep 5 years	Discounted Present Value (7.5%): $38,194
Interest (= 20%) Keep 6 years	

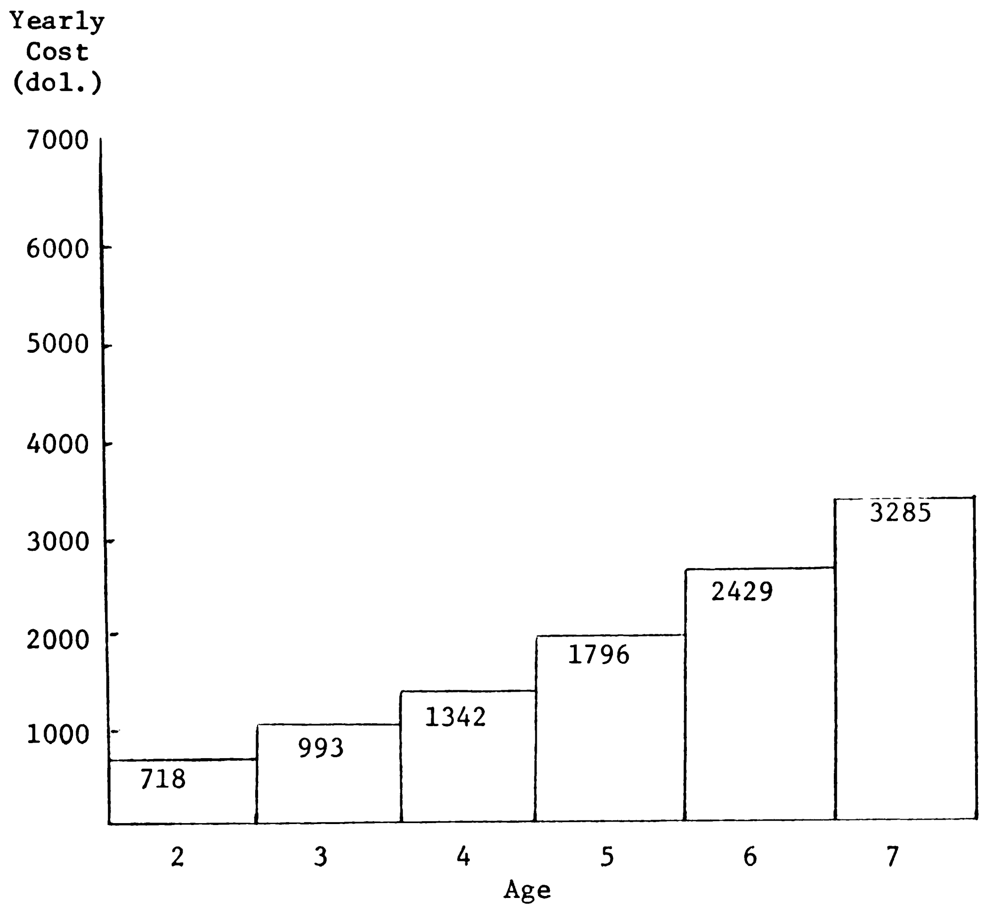

Figure 18. The Distribution of the $10,560 of Total Repair Costs for Years Two Through Seven for a Two-Row Combine with a 1-Exponential (λ = .3) Distribution

Optimum Policy

Keep 5 years

Average Yearly Cost: $2,358

Discounted Present Value (7.5%): $36,231

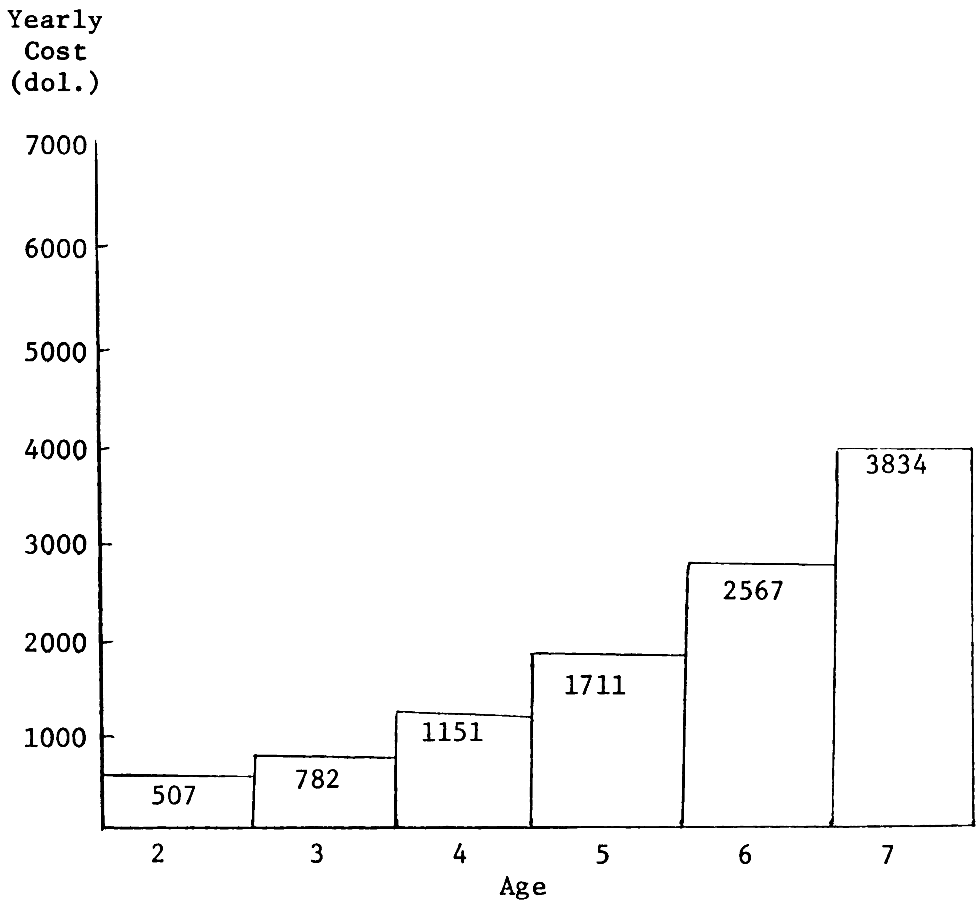

Figure 19. The Distribution of the $10,560 of Total Repair Costs for Years Two Through Seven for a Two-Row Combine with a 1-Exponential (λ = .4) Distribution

Optimum Policy

Keep 5 years

Average Yearly Cost: $2,237

Discounted Present Value (7.5%): $34,553

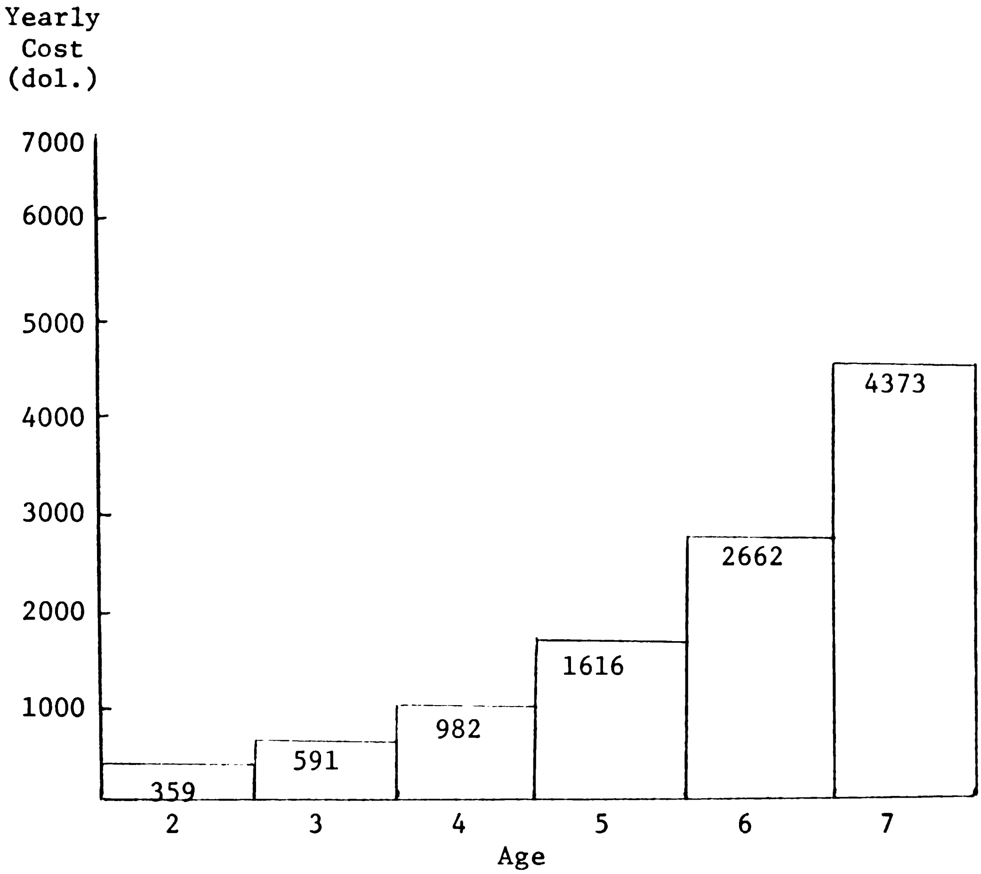

Figure 20. The Distribution of the $10,560 of Total Repair Costs for Years Two Through Seven for a Two-Row Combine with a 1-Exponential (λ = .5) Distribution

Optimal Policy

Keep 5 years

Average Yearly Cost: $1,808

Discounted Present Value (7.5%): $28,776

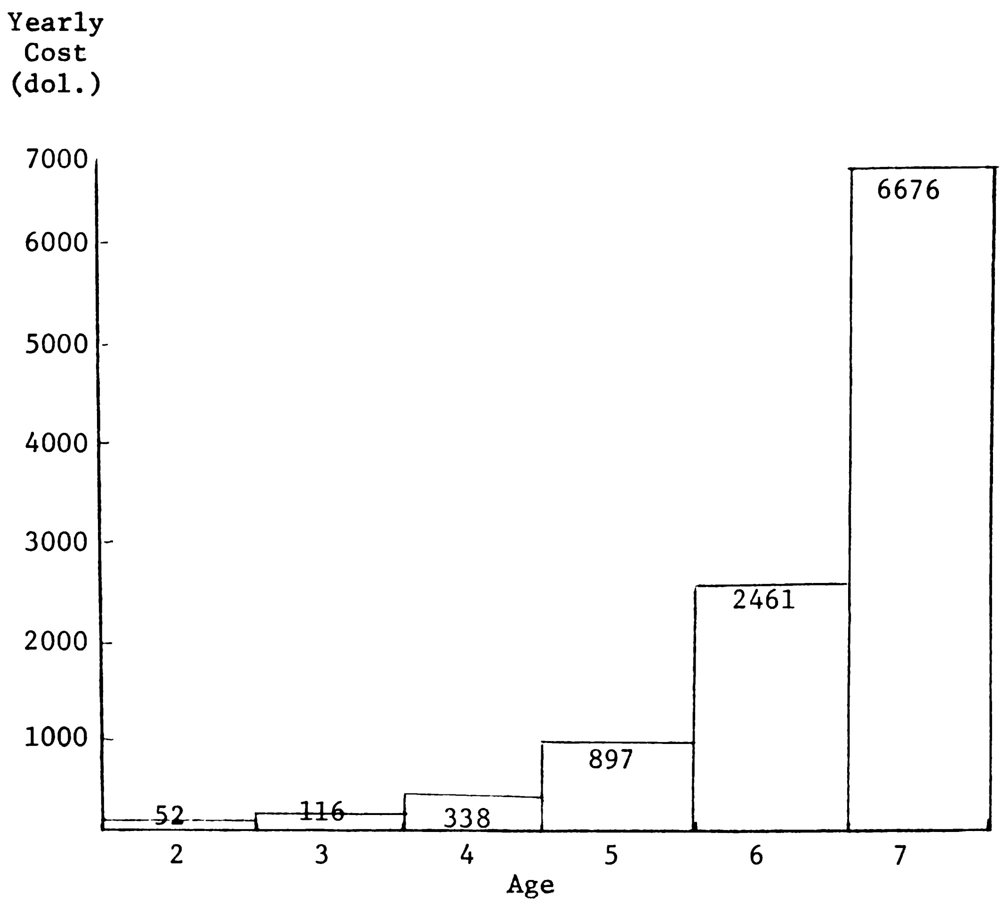

Figure 21. The Distribution of the $10,560 of Total Repair Costs for Years Two Through Seven for a Two-Row Combine with a 1-Exponential (λ = 1.0) Distribution

Table 41. Summary of the Optimum Replacement Period for the Eight Different Distributions for the $10,560 of Total Repair Costs

Interest rate	Number of Year "Keep"							
	Armstrong	Uniform[a]	Increase	λ = .2	λ = .3	λ = .4	λ = .5	λ = 1.0
0.0%	6	7	5	5	5	5	5	5
5.0%	6	7	5	6	5	5	5	5
7.5%	7	7	5	6	5	5	5	5
10.0%	7	7	5	6	5	5	5	5
12.5%	7	7	5	6	5	5	5	5
20.0%	7	7	6	7	6	5	5	5
Average yearly cost	2814	3813	3098	3412	3113	2850	2632	2013

[a]The machine is replaced after seven years regardless of costs.

Table 42. The Effect of Different Hours of Use on the Optimum Replacement Pattern and the Corresponding Cost Using the First Set of Data[a]

Optimum replacement pattern[b]	Average Yearly Cost			
	100 hours (dol.)	200 hours (dol.)	300 hours (dol.)	400 hours (dol.)
Keep 4 years	2736	3036	3336	3636

[a]The "keep" cost include $360 per year for obsolescence cost, i.e., one-year old machine has $360 obsolescence cost, two-year old machine has $720 obsolescence cost, etc.

[b]The optimum replacement policy is identical for all hours of use.

Table 43. The Optimum Replacement Pattern and Corresponding Costs for a Two-Row Combine Used 100, 200 and 300 Hours per Years Using the Bowers Data[a]

Hours of use	Optimum policy	Average yearly cost (dol.)
100	Interest $\leq$ 12.5% keep 5 years Interest = 20.0% keep 6 years	2405
200	Keep 4 years	2715
300	Interest $\leq$ 12.5% keep 3 years Interest = 20.0% keep 4 years	3068

[a]The costs for keeping include $360 (3% of new cost) per year of age for obsolescence.

in Table 43. With this data the length of time the machine is kept decreases as the hours of use increase.

Level of Machinery Management

The ability of the farm manager with regard to handling machinery has a large effect on the level of machinery repair costs. The level of machinery management is reflected in the maintenance of the machines, in the handling of minor repairs and problems and in the operating of the machine. Three assumptions are made as to how the management of machinery affect the costs of keeping and trading machinery. The three assumptions are:

1. Management affects the level of repair costs but has no effect on trade-in value and obsolescence.
2. Management affects the level of repair costs and the trade-in value but has no effect on obsolescence.
3. Management affects the level of repair cost, the trade-in value and obsolescence.

The effect of machinery management on optimum machinery replacement is studied using each of the assumptions. Six management levels are used. The levels are: .75, .90, 1.0, 1.1, 1.25, and 1.50 where each level means a person in the given management level will incur that proportion of the repair costs indicated by the Armstrong function. The repair costs using the function are given in Appendix Table D. 1. For instance, the level .75 is the best management level with these managers only incurring 75 per cent of the repair cost indicated by the function.

Using the first assumption that only repair costs are affected by management, the cost of keeping changes as much as the repair cost with the three per cent per year obsolescence remaining constant. With the trade-in cost constant the cost of trading only changes as much as repair costs in the first year change. Table 44 pictures the optimum replacement pattern for each management level for each interest rate and the average yearly cost without discounting for each management level. As the level of management declines repair costs increase in each year. The optimum frequency of replacement increases as do the average yearly costs.

Table 44. The Effect of Alternative Levels of Machinery Management on the Optimum Replacement Pattern and Cost for a Two-Row Combine Given the Assumption that Management Affects only Repair Costs[a]

Interest rate	Number of Years "Keep"					
	.75	.90	1.0	1.1	1.25	1.50
0.00%	4	4	4	4	4	4
5.00%	4	4	4	4	4	4
7.50%	4	4	4	4	4	4
10.00%	5	4	4	4	4	4
12.50%	5	5	4	4	4	4
20.00%	5	5	5	5	4	4
Average yearly cost	2818	2949	3036	3124	3254	3473

[a]Uses the first set of data and includes three per cent of new cost per year of age charge for obsolescence.

With the second assumption that management affects repair costs and trade-in value only, the cost of keeping is the same as with the first assumption; however, the trade-in value of the machine is now assumed to be partially dependent on machinery management level of the manager. The trade-in value is now determined by dividing the value calculated with the Peacock-Brake function by the various management level: .75, .90, 1.0, 1.25, 1.50. Table 45 presents the optimum number of years to keep the combine with each management level and the resulting average yearly cost. With this second assumption the optimum frequency of replacement increased as the management level deteriorated; however, note also the much larger increase in average cost with declining management.

Table 45. The Effect of Alternative Levels of Machinery Management on the Optimum Replacement Pattern and Cost for a Two-Row Combine Given the Assumption that Management Affects Repair Cost and Trade-in Value[a]

Interest rate	Number of Years "Keep"					
	.75	.90	1.0	1.10	1.25	1.50
0.00%	3	4	4	4	4	4
5.00%	3	4	4	4	5	5
7.50%	3	4	4	4	5	5
10.00%	3	4	4	5	5	5
12.50%	3	4	4	5	5	5
20.00%	4	4	5	5	5	5
Average yearly cost	2298	2796	3036	3249	3530	3932

[a]Uses the first set of data and includes three per cent of new cost per year of age charge for obsolescence.

With the third assumption repair costs, trade-in value and obsolescence charges are all affected by the management level. The repair costs and the trade-in value are affected as in the previous assumptions and the obsolescence charges are affected like repair costs. Table 46 presents the optimum replacement frequency and the average yearly cost for this assumption. No overall pattern is shown in the frequency as the management level changes, but the costs increase rapidly as the management level deteriorates.

Table 46. The Effect of Alternative Levels of Machinery Management on the Optimum Replacement Pattern and Cost for a Two-Row Combine Given the Assumption that Management Affects Repair Costs, Trade-in Value and Obsolescence Charges[a]

Interest rate	Number of Years "Keep"					
	.75	.90	1.00	1.10	1.25	1.50
0.00%	3	4	4	4	4	4
5.00%	4	4	4	4	4	4
7.50%	4	4	4	4	4	4
10.00%	4	4	4	4	4	4
12.50%	4	4	4	4	4	4
20.00%	4	5	5	5	5	5
Average yearly cost	2208	2742	3036	3302	3665	4202

[a]Uses the first set of data.

Obsolescence Charges

As the machine the farm manager is using increases in age, his present machine becomes increasingly inefficient in comparison to a new machine. The degree of inefficiency depends on the type of machine, its age, and the improvements in the new machine. For this study obsolescence charges are calculated as a per cent per year of the new cost. Four levels are used: 0.0, 3.0, 6.0, and 10.0 per cent. The new cost of the two-row combine is $12,000. Table 47 illustrates the effect of the rate of obsolescence of the optimum replacement frequency and corresponding average yearly cost. The length of time before trading decreases and the cost increases as the obsolescence rate increases.

Table 47. The Effect of Different Levels of Obsolescence Cost on the Optimum Replacement Pattern and Cost for a Two-Row Combine

Interest rate	Number of Years "Keep"			
	0.00%	3.00%	6.00%	10.00%[a]
0.00%	6	4	3	3
5.00%	6	4	3	3
7.50%	7	4	3	3
10.00%	7	4	3	3
12.50%	7	4	3	3
20.00%	7	5	4	3
Average yearly cost (dol.)	2359	3036	3514	3994

[a]3, 6, and 10 per cent per year of age.

Increasing Cost

When a farm manager decides to purchase a new machine, he usually finds that the price is considerably above the amount he paid for the machine he presently owns. This price rise can be a large increase with a constant price thereafter or a gradual increase. Two different price increases are used here. The first increase is of $1000 the year after the farm manager purchased his new combine while the second increase is 5 per cent of the new cost of the first machine per year ($600 per year for the two-row combine). Repair costs, trade-in value and obsolescence charges remain the same. The Optimum Policy and Corresponding Cost for the two types of increases and no increase is shown in Table 48. Note that the one-show increase delays the trade-in time significantly and the steady increase delays trade-in slightly under certain circumstances.

Interest Rate

The previous tables have adequately illustrated the impact of increasing interest rates in delaying optimum trade-in time. As the interest rate rises future costs are discounted more and more. Since the largest cost of machinery is at trade-in time, higher interest rates often delay the optimum trade-in time one year.

Optimum Replacement in the Corn Harvesting System

Using the base values except for size of enterprise, the average hours of use for the two-row combine are 128 and 330 for 200 and 500 acres respectively. For the four-row an average of 70 hours and 179 hours are used for 200 and 500 acres respectively. The optimum replacement frequencies and costs are found in Table 49 using the Armstrong repair costs function and the Peacock-Brake function for trade-in value and no obsolescence charge. The two-row combine has a

Table 48. The Effect of Increasing Purchase Cost for a New Two-Row Combine on the Optimum Replacement Pattern[a]

Interest rate	Number of Years "Keep"		
	No increase	$1,000[b]	5% per year[c]
0.00%	4	4	4
5.00%	4	4	4
7.50%	4	4	4
10.00%	4	4	5
12.50%	4	5	5
20.00%	5	5	5
Average yearly cost (dol.)	3036	3111	3638

[a]Uses the first set of data with three per cent per year of new cost charged for obsolescence.

[b]Increase is assumed to be the year after purchase with no further increases expected.

[c]$600 per year for the $12,000 two-row combine.

Table 49. The Optimum Replacement Policy for the Two-Row and Four-Row Combine Used in the Corn Harvest Simulator for 200 and 500 Acres[a]

Interest rate	Number of Years "Keep"			
	2-row 200 A.	2-row 500 A.	4-row 200 A.	4-row 500 A.
0.00%	6	6	6	6
5.00%	6	6	6	6
7.50%	7	7	7	7
10.00%	7	7	7	7
12.50%	7	7	7	7
20.00%	7	7	7	7
Average yearly cost	2376	2982	2936	3304

[a]Based on the actual hours used for base values.

new cost of \$12,000 and the four-row costs \$16,000. As the results previously showed, the number of hours of use does not affect the replacement using this set of data. The size of the machine has no effect either since the same values are multiplied with a different initial cost.

Footnotes

1. The function is

$$ARC = NC\ [(-.0197X_1 + .0087X_1^2 - .00053X_1^3) + (.02 + .00025X_2)]$$

where:

ARC = annual repair costs
NC = new cost of machinery being considered
X_1 = age of machine
X_2 = hours of annual use.

The source is:

An unpublished working paper written by Dr. David L. Armstrong for the corn simulation model. The working paper is based upon the following work:

Armstrong, David L. and J. Edwin Faris, Farm Machinery Costs, Performance Costs, and Combination, California Agricultural Experiment Station and the Giannini Foundation of Agricultural Economics, Giannini Research Report 273, March 1964, pp. 13-14.

and

Huber, S. J., "Depreciation and Repair Cost of Self-Propelled Combines," Transactions of the ASAE.

2. The function is: $\hat{y} = (60.7 - 3.7X_1)\ NC$

where:

$\hat{y}$ = the estimated "market value" of the used machine
X_1 = age of the machine
NC = new cost of the machine.

The source is:

Peacock, David L. and John R. Brake. What is Used Farm Machinery Worth? Research Report 109, Michigan State University Agricultural Experiment Station, East Lansing, March 1970, p. 7.

3. Bowers, Wendell. Modern Concepts of Farm Machinery Management, Stipes Publishing Co., Champaign, Illinois, 1970, pp. 18, 35.

CHAPTER VII

ANALYSIS OF THE REPLACEMENT RESULTS AND INTEGRATION OF THE SHORT-RUN AND LONG-RUN ANALYSIS

The analysis in this chapter is divided into two parts. The first part is concerned exclusively with the long-run replacement decision. In this first part each of the selected seven variables is analyzed to determine the importance of its effect on the replacement decision. In the second part of the chapter the short-run and the long-run analysis are integrated. Particular attention is placed on determining the effect on the optimum replacement decision of changes in variables affecting the harvesting period. The effect on income from the individual harvesting period of changes in the variables affecting the replacement decision is also considered.

Analysis of the Long-run Replacement Results

Due to the nature of the selected variables and the nature of the data required, a ranking of the variables similar to the one used for the harvesting period is impossible for two reasons. The first reason is that changes equivalent to those used with the short-run variables would be impossible. By its nature repair cost data must be situation-specific. This means that replacement decisions must be based on the individual situation rather than general conclusions.

With this situation-specific data, rankings would be accurate only for that situation.

Although specific rankings cannot be attained, important conclusions can be reached. An indication of the potential importance of each of the seven selected variables can be found. A determination as to which variables always have an effect and which ones only have an effect under certain circumstances can be made. Finally, a distinction can be made concerning the changes that increase the frequency of replacement and those that decrease this frequency.

On the pages that follow, each of the seven selected variables is considered. Conclusions based on the ideas expressed in the previous paragraph are reached. The reader should keep in mind that although a large part of the analysis concerned the replacement frequency, the ultimate objective is to minimize cost over time.

Repair Function

The discrepancy between the two sources of repair cost data used is rather large. Assuming a 7.5 per cent interest rate, the optimum replacement period is seven and six years for the two sets of data used. The average yearly cost with no discounting also has no consistency with values of $2359.00 and $2090.00. Since neither of these sources of data or any other source is recognized as being accurate, replacement decisions must be situation specific. Not only can the farm manager provide his own data on repair costs, trade-in values and obsolescence charges, he can include any other pertinent charges for either keeping or trading. These additional costs become particularly important when the farm manager trades for a non-identical machine.

Shape of the Repair Cost Function

Although it is not very apparent, a distinct pattern is present between the shape of the function and the frequency of replacement. With the very unrealistic uniform function the machine is not replaced until it cannot survive for another year. There is no reason to replace since the cost of keeping is unchanged the following year. As the slope of the function becomes steeper, the frequency of replacement increases since the increased cost the following year must be averted. This relationship is true up to a certain steepness. Beyond this point the repair costs become so weighted to the last year or two that the optimum replacement frequency increases again. The relationship between the shape of the repair costs and the average cost is much more direct. As the curve increases in steepness, the average cost declines since more of the fixed total amount can be averted.

The shape of the repair cost function certainly has an important effect on the replacement frequency. To the farm manager its importance is only through the effect on his replacement policy. It is not important to him in the sense that he can affect the shape. If he could affect the shape, he would delay as much of the repair costs as long as possible and then trade before the repairs were made.

Number of Hours of Machine Use

As was indicated previously, the effect of the number of hours of machine use on optimum replacement frequency depends on the source

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of the data. Two further points require analysis. The first is the effect on the ownership cost while the second is the relative importance of hours of use and age of the machine in determining the magnitude of the repair cost. The first point is simple that increased hours of use increase the average cost.

The relative importance of hours of use and age of the machine on repair costs also depends upon the source of the data. Table 50 illustrates this fact. With the data from the Armstrong function the age is of much greater importance; with the Bowers data the hours of use have a greater effect on repair costs. Once again the answer must be determined by the specific data used.

Previously the difference between the two sources of data was described as rather large. Based on Table 50, the reasons for this difference can be determined. The first difference is that the Armstrong function in general has a higher level of repair costs when the machine is new. Secondly, with the Armstrong function the major portion of the increase in repair costs comes from increasing age. With the Bowers data, there is some increase in repair costs with age, but the cost increases much more rapidly by expanding the hours of use especially with older machines.

Level of Machinery Management

The level of machinery management has a large effect on both the optimum replacement frequency and the corresponding average cost. The effect on the frequency depends upon the assumption regarding which costs management affects. The conclusion can be made that under all circumstances management has an effect on the optimum frequency.

Table 50. The Effect on Cost of an Additional 100 Hours of Use Versus an Additional Year of Age on Repair Costs for a Two-Row Combine

Age of machine (years)	Armstrong Data[a]		Bowers Data[b]	
	One year[c] (dol.)	100 hours[d] (dol.)	One year[c] (dol.)	100 hours (dol.)
1	122	300	168	208
2	165	300	252	426
3	259	300	336	732
4	315	300	432	1110
5	333	300	536	1578
6	313	300	592	2118
7	255	300	696	--

[a]See footnotes 1 and 2, Chapter VI, p. 137.

[b]See footnote 3, Chapter VI, p. 137.

[c]Repair costs at age given minus repair costs previous year with no obsolescence charge for 200 hours.

[d]Average of difference in repair costs between 100 and 200, and 200 and 300 hours.

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The only way for the effect to be non-existent would be for management to affect the repair costs, obsolescence charges and price paid for a new machine in exactly the same way. Management may affect trade-in value in that manner but not the difference between new cost and trade-in value. The effect of management on average cost, on the other hand, is consistent. Poorer management always produces increased average cost.

The effect of the level of management on the optimum replacement frequency depends on whether the cost of keeping or the cost of trading is affected more. If the management level affects the cost of keeping more, the frequency decreases as the management level declines. This is the case with the first assumption that machinery management affects repair costs but does not affect obsolescence charges or trade-in value. When the management level effects the cost of trading more than the cost of keeping, the frequency increases as the management level declines. The use of the second assumption creates this situation since the cost of trading changes more as the trade-in value and repair costs are affected but the obsolescence charge is not. With assumption three where all three costs are changing no conclusion can be reached since the cost of trading is affected more if the machine is one or two years old and the cost of keeping is affected more if the machine is three or more years old. For a three year old machine which is the critical age the cost of keeping is affected only slightly more than the cost of trading. Table 51 shows the optimum frequency with 7.5 per cent interest and the average yearly cost with no discounting for each of the management levels under each of the assumptions.

Table 51. The Optimum Replacement Frequency and Corresponding Average Cost for Each Management

Table 51. The Optimum Replacement Frequency and Corresponding Average Cost for Each Management Level and Each Assumption Concerning the Effect of Machinery Management on Keeping and Trading Costs for a Two-Row Combine

Management level	Assumption 1		Assumption 2		Assumption 3	
	Optimum frequency[a]	Ave. yearly cost (dol.)[b]	Optimum frequency	Ave. yearly cost (dol.)	Optimum frequency	Ave. yearly cost (dol.)
.75	4	2818	3	2298	4	2208
.90	4	2949	4	2796	4	2742
1.00	4	3036	4	3036	4	3036
1.10	4	3124	4	3249	4	3302
1.25	4	3254	5	3530	4	3665
1.50	4	3473	5	3932	4	4202

[a]With 7.5 per cent interest.

[b]No discounting.

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Obsolescence Charges

Since obsolescence charges increase the cost of keeping, increases in these charges increase the frequency of optimum replacement and the average cost. Although the effect of these charges is easily recognized, the actual value is extremely difficult to determine for two reasons. First, the charge depends on the type of machine, improvements in that type of machine since the one being used was purchased, age of the machine, hours of use of the machine and characteristics of the machine operator. These numerous variables make imperative the determination of obsolescence charges for each situation. The second problem is now encountered. Even in this individual situation, the calculation of the actual loss from not having the newest machine is extremely difficult. This loss will vary from one machine to another and depending upon the field conditions. Even though this determination is difficult and may have to be estimated in many instances, obsolescence changes must be included when determining optimum replacement costs because its effect is great. A cost per acre or per hour may be more accurate than the percentage of new cost used in this study.

Increasing Cost

With increasing costs for the new machine to be traded for, the cost of trading increases so the optimum replacement frequency should decrease. Although this relationship is true for the two cases studied, it does not necessarily hold. In situations where a lump sum increase occurs immediately after purchase as in the first case studied, the relationship holds; however, when the increase is greater eac

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each year, two forces are at work. The first is the increased cost of trading tending to decrease the frequency. The second force is the tendency to trade sooner to avoid the upcoming increases. Depending upon which force is stronger, the frequency can increase or decrease. Of course, the second force increases in strength as the yearly increases become larger.

Information concerning price increases that will apply to all farms is easier to acquire than the types of information discussed previously. The general inflation rate and/or average price increases for farm machinery could be used. Once again, however, using figures for individual farms is more accurate since the farm manager knows or can determine what price increases are likely in his locality for that particular machine.

Interest Rate

As explained previously, increases in the interest rate decrease the optimum replacement frequency by making the delay of trade-in profitable. This interest increase does not decrease the actual cost of the machine unless the money is borrowed; however, the increase does improve the opportunity of added profit from the use of the funds in other investments. As shown in the results presented previously, increases in the interest rate often delay purchase for one year.

General Conclusions

From the above analysis of each variable the conclusion is easily reached that any of the variables studied can change the optimum replacement frequency and that all of the variables affect the average cos

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cost. Any ranking of the variables seems impossible because their importance depends on the situation before the change and the source of the data used. Emphasis must once again be placed on the importance of using data from the actual situation being studied.

Although the effect of each variable cannot be ranked, the effects can be separated into those that increase the optimum replacement frequency and those that decrease this frequency. In general, the optimum replacement frequency increases when the cost of keeping is increased relative to the cost of trading. The following changes in the variables tend to increase this frequency:

1. Increases in the slope of the repair cost function until the slope becomes so steep that nearly all of the repair costs are in the last year or two.
2. Additional hours of use.
3. Declining levels of machinery management when the assumptions are such that the cost of trading is affected more.
4. Increases in obsolescence charges.
5. Increasing cost for the new machine when the yearly increases are large.

When the cost of trading increases relative to the cost of keeping, the optimum replacement frequency decreases. The following conditions tend to decrease this frequency:

1. Increases in steepness of the repair cost function when it is already very steep.
2. Declining levels of machinery management when the assumptions are such that the cost of keeping is affected more.

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3. Increasing cost for the new machine unless the yearly increases are large.

4. Increases in the interest rate.

The reader may be wondering how these conclusions can help a farm manager. The number of variables the farm manager must be cognizant of when he considers his replacement decision can be reduced. Assuming that the farm manager has already calculated his own repair costs and trade-in value, the variables "source of the cost data" and "shape of the cost function" are no longer variables. The number of variables to be considered is thus reduced to five--number of hours the machine is used, level of machinery management, rate of obsolescence, cost of the new machine and the interest rate. Since the situation being considered is for a specific farm manager, the level of machinery management can be considered constant leaving only four variables. Of these four, the farm manager must consider the cost of the new machine and the interest rate. The number of hours of use only has to be considered if it will change significantly in the relevant future. A common method of considering obsolescence charges is to assume they are reflected in the decreasing value of the used machine.

Integration of the Short-run and Long-run Analysis

Since a new machine is used in the first year and only three years are used, the conclusions of the previous section would not affect the simulator as it was used in this study. If a longer period had been used, however, this conclusion would not be correct. The optimum replacement period is seven years using the repair cost

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function in the simulator and no obsolescence charge. If, for example, eight years of corn harvest are simulated with a four-row combine harvesting 500 acres, the decision as to whether to keep or trade the seven year-old combine depends on the length of run being considered. For this production period the cost to repair the combine is $3164.00 while the cost of trading is $9252.00. The average yearly cost of the policy of trading every seven years is $3036.00 while the average yearly cost if the manager kept one additional year and then traded would be greater. Therefore, in the seventh year the farm manager would trade for a new combine to minimize his costs over time even though keeping would be much less expensive for the present harvest season.

Changes in many of the variables that have been studied for one length of run have an effect when the other length of run is considered. The effect of the variables affecting the optimum replacement frequency on the short-run model is simply that a machine may be traded more or less frequently. The effect on costs in the individual harvesting period may be substantial; however, the long-run effect on cost will be the change in average yearly cost. The effect of each long-run variable on the short-run is simply the effect presented in the first section of this chapter applied to the individual harvest period.

The effect on the optimum replacement frequency of the variables studied for the harvest period is not nearly as simple. The effect of each of these variables on the costs of keeping and trading must be determined. The effect of these changes in costs on the optimum re

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replacement frequency is then determined. On the following pages each of the nine variables studied for the short-run is considered.

Size of the Enterprise

In general increases in size increase the hours of use. The effect would be the same as with changes in hours of use. One further condition must be considered, however. When the size of enterprise changes enough so that the present machine is inefficient, complication results. For example, if the size of enterprise increases, the probability of loss from failure to harvest may increase to an alarming point. Some amount should be added to the cost of keeping to cover this possibility of loss. Of course, the cost of trading would also increase since a larger machine would be traded for.

Price

The effect of the price of corn on the optimum replacement frequency works through the obsolescence charge. The result of obsolescence usually is increased field losses. With changes in the price the loss from obsolescence changes thus altering the cost of keeping. With changes in the cost of keeping the optimum frequency may change. As prices increase, replacement tends to occur sooner. Since the price seldom changes more than a few cents a bushel, the effect of the price of corn on the optimum replacement frequency is very small. Many if not most farm managers put too much emphasis on the crop price when determining their machinery replacement policy.

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Yield

The effect of yield is similar to the effect of price. As yield changes, the obsolescence loss will change thus altering the cost of keeping relative to the cost of trading. This effect may become more important as yield increases since an older machine may be more inefficient with large yields than with lesser ones. Also, with higher seed and fertilizer investments and greater yields, the potential loss from not completing harvest increases, creating the possibility that a larger machine may be more profitable. Consequently the potential on replacement policy with changes in yield is greater than the effect of changes in price. Once again though many farm managers overestimate the importance of this effect.

Opportunity Cost

The labor cost has an effect on the optimum replacement frequency only when the new machine requires less labor because of improvement in design or increased size. Even in these two cases there would be no effect using the cost structure of this study. The needed costs could, however, be easily included. In this case increased cost for labor would tend to increase replacement frequency. The above effect is a part of the process of mechanization continuing today.

Hours

As with the labor cost, the effect of the hours in the work day is only relevant when the manager is trading for a machine with greater capacity. In this case increasing the work day would decrease the pro

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profitability of trading for a new combine. Any decrease in the work-day would have the opposite effect of increasing the profitability of trading. This variable and the previous labor cost often go together with labor costs increasing and labor becoming unavailable for long-hours of work.

Grain Moisture and Loss

As with the two previous variables, the effect of the grain moisture criterion for commencing harvest and of the loss from failure to complete harvest during the harvest period is nonexistant unless the new machine has more capacity. When the new machine is larger, decreases in the grain moisture criterion causing a later harvest and increases in the loss tend to increase the optimal frequency. Movement in the opposite direction creates the opposite effects.

Since changes in the average temperature and rainfall are so unpredictable and so limited to the short-run, the effect of these two variables on the optimum replacement frequency can easily be considered nonexistent unless the manager is trading for a larger machine. In general, the effect of the short-run variables on replacement policy is not great. Changes in size easily have the greatest effect. Rather small effects are felt from changes in several other variables especially if the machine to be purchased is nonidentical.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

Since all previous efforts are lost if the crop is not harvested, harvesting is the most critical phase in a crop production system. Many variables must be considered by the farm manager. When making harvesting decisions, the farm manager must be cognizant of two views of the harvesting system. The first view is of the individual harvesting period, and the second considers the purchase of a major machine. In light of the importance of correct decision-making during harvest, the objective of this study was to determine and evaluate the effects of nine variables on the individual harvest period and seven variables on machinery replacement decisions.

The computer model used to determine the effect of these variables included a simulator of a corn harvesting system to determine the effect on the individual harvest and a dynamic programming replacement model to consider the purchase of a major machine. Using actual harvest conditions for 1966-1968 as a base, a wide variety of weather, yield, and price conditions were simulated for various sizes of enterprise with a two-row and a four-row combine. The replacement routine was then used to determine the optimum time to purchase a new machine using the two-row combine in a variety of situations.

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The effect of nine variables on management income from the individual harvest period--loss due to failure to complete harvest during the harvest season, size of enterprise, hours in the work day, grain moisture criteria for starting harvest, opportunity cost of labor, average temperature, additional rainfall, price and yield--was considered. When these variables are ranked according to their effect on management income from the individual years; size of enterprise, temperature, price and yield appeared to change average income by 20 per cent or more. The rankings, however, are very dependent upon the individual situation. Different weather conditions are found to have a great effect on the rankings.

The rankings of the effect of the variables on management income acquired consistency when the harvesting situations were divided into those situations in which the harvest is completed and those in which it is not. Four variables--size of enterprise, hours in the work day, grain moisture criterion, and additional rainfall--actually had opposite effects on the farm manager's income depending upon whether harvest is completed during the harvesting period. When harvest is completed during the harvesting period, four variables have an effect on management income in excess of 20 per cent (of average income) while the effect of the other five variables is less than 10 per cent. The four variables having a major effect in decreasing order of importance are: size of enterprise, price, temperature and yield.

In the less frequent situation where harvest is not completed during the harvesting period, more variables occupy a major role since harvesting time is now of the essence. The four variables of prime importance when harvest is completed--size of enterprise, price, temperature and yield--retain their important effect. Loss from failure to complete harvest and hours in the work day also create changes in management income in excess of 20 per cent (of average income). Changes in the grain moisture criterion and rainfall also created changes in income in excess of 20 per cent (of average income) under certain circumstances. In general the variables size and loss had the greatest effect on management income with effects in excess of 100 per cent under certain circumstances.

The importance of the selected variables in "good" and "bad" years is of interest to the farm manager. "Good" and "bad" years are looked at first in terms of price and/or yield and then in terms of the weather during harvest. In terms of relative importance of the variables, "good" and "bad" price-yield conditions have the same effect. The effect goes back to the question of completion of harvest. In terms of the actual dollar value of the change, the effect is greater during a "good" year because the same change now affect more bushels and/or has a larger value per bushel. In terms of weather conditions, the "good" year is represented by the conditions when harvest is completed during the harvest season and the "bad" year by conditions when harvest is not completed.

Changes in these nine variables also have an effect on the relative income positions of the two-row and the four-row combines. In order to get consistent results, the situations must be divided into three categories: those in which both combines finish harvest, those in which only the four-row completes harvest and those in which neither combine completes harvest during the harvest period. Only in the second category where only the four-row completes harvest did any of the variables affect the relative income positions. In this category the size of enterprise, hours and loss variable were extremely important (greater than 70 per cent change in income), and rainfall (22 per cent) and grain moisture (17 per cent) variables had an important effect.

Of the nine variables studied, three--size of enterprise, hours in the work day and grain moisture criterion--can be largely controlled by the farm manager. The profit maximizing value for each of these variables could be determined using the gain (in dollars) from increases in the values for the three variables with completion of harvest during the harvesting period, the loss (in dollars) from increases if harvest is not completed and the probability (in per cent) of completing harvest during the harvest season. The maximizing length of the harvest day can be updated periodically throughout the harvest period.

The effect on the timing of the purchase of a major machine of seven variables--the farm situation from which the repair data is derived, the shape of the repair cost function, the number of hours the machine is used, the level of machinery management, the rate of obsolescence, the cost of the new machine being considered and the interest rate--was considered. Each of the variables studied was found to have a potential effect large enough to alter the year in which the farm manager would trade if he were minimizing costs over time. Changes in the variables resulted in optimum policies of keeping the combine from three to seven years. The farm situation from which the data came was found to have the greatest effect on the replacement decision. Since no set of repair data has been found that is representative of all farms or even of a class of farms, the effect of the other variables depends upon the farm situation being considered. Because of the above situation, replacement decisions must be based on the individual situation rather than general policies.

Even though few conclusions can be reached relative to the magnitude of the effect of the selected variables, conclusion can be reached regarding the direction of the effect. Additional hours of use and increase in the obsolescence charges increase the likelihood of purchasing the new machine. Increases in the interest rate delay the optimum time to trade for the new machine. Increases in the cost of the new machine tend to delay the time to trade unless the trade can be made the year prior to a large price increase.

The situation for the individual farm manager is not as complex as it initially appears. Assuming that the farm manager has calculated his own repair cost date, the variables source of the cost data, shape of the cost function and the level of machinery management are constant. Only four variables remain. If the farm manager does not plan to change the hours of use of the machine, that variable can be disregarded. Furthermore, many farm managers let the declining value of the used machine (with age) represent the obsolescence charge. The farm manager must now consider (beside the age of his present machine) a maximum of four variables and a minimum of two--cost of the new machine and the interest rate.

Changes in eight of the nine variables affecting the individual harvest had almost no effect on the replacement decision. The only exception was the size of the enterprise which affected the replacement decision as a change in the hours of use of the machine. Changes in the seven variables affecting the decision to purchase machinery have an effect on the income from the individual year through the average minimum cost. For changes in the seven variables in the relevant range, this affect amounts to only a few dollars a year.

The above findings have important implications on how and when the farm manager makes decisions concerning harvest. The first of these decisions must be made in the winter months prior to the new harvesting season. Taking into account a number of years, the farm manager must decide whether to purchase any new machinery. The major decision for the harvesting system concerns a combine. At the same time, the manager must use his potential gains, losses and probabilities of completing harvest with the combine he owns to determine his profit maximizing size of enterprise. The acreage thus determined is the maximum possible for that enterprise. This maximum may be reduced by limitation during the planting or growing seasons, by acreage limitations within the firm or by the profitability of the enterprise relative to other enterprises. Throughout this decision-making process, the farm manager must keep in mind possible changes in the variables found to have an important effect on income.

As the harvesting season approaches, the farm manager must determine the profit maximizing date to start harvesting using the gain from delaying the harvest if it is completed, the loss if it is not completed, and the probability of completion. The manager can use the expected hours in the work-day to determine when to start harvesting. During the harvest the hours worked can be adjusted according to the success of harvest to date. Although few farm managers explicitly follow this process, the process is implicit in the actions of many farm managers.

Realizing the above, a number of conclusions concerning the actions of farm managers can be reached:

1. Farm managers may be justified in maintaining overcapacity of 20 to 30 per cent. The relatively small cost of this overcapacity may prevent losses in income of 20 per cent or more.

2. Farm managers, particularly those with large acreages, may be justified in trading their equipment, especially harvesting equipment, every two or three years.

3. In years that the grain moisture content is high, farm managers may be justified in starting corn harvest even though the moisture content is abnormally high.

4. The optimum size of enterprise for each farm manager may depend significantly upon whether he is a profit maximizer, a risk averter, or a risk taker.

CHAPTER IX

IMPLICATIONS FOR FUTURE RESEARCH

The early stage of development of the simulator and the limited scope of this study produced a number of limitations. Probably the most important was that harvest is an important subsystem of a much larger production system. Studying this subsystem by assuming the remainder of the system essentially constant ignores many important relationships. The impact of planting date and the effect of an extremely unfavorable growing season on the harvesting system are two examples of these relationships. Many of these relationships could be partially studied by altering the initial conditions facing the harvesting system.

Many aspects of the harvesting system were not fully developed in the model used for this study. The criterion for determining when to start harvest was not fully developed. Also, the harvesting of all corn remaining in the field on December 1 at one time was an unsupportable assumption. The greatest obstacle to studying the harvesting system was the lack of any drying and storage facilities.

Given these initial limitations in the simulation model used, a number of limitations are evident in the study itself. In addition to the nine variables studied, others could have been added. Two of the most important additions could have been the efficiency of the combine operator and field losses due to lodging and harvest. In ranking the nine variables relative to their effect on income, the assumption that all of the changes were equal is questionable. The changes in size of enterprise (100 acres) and temperature (five degrees) seem particularly large. In studying the effects of changing variables, little attention was paid to simultaneous changes in more than one variable.

Although the replacement routine was much smaller and therefore more easily developed, limitations are evident. The most important was the restriction to two alternatives and seven states. This restriction ruled out any consideration of trading for a used combine. The use of only seven variables and the assumption that only identical machines are purchased limits the value of the conclusions concerning machinery replacement.

The analysis of each of the models suffers from the lack of sufficient valid data. Although the data used in the simulator had never been used in that manner previously, the greatest deficiency was the lack of tractability data for December. The replacement routine suffers from a lack of consistent repair data.

Based upon these limitations and the conclusion of the study, a number of implications for future research in this area can be made. From the results of this study and of others using the harvesting model, the conclusion seems to be clear that the simulation of agricultural production systems should continue. The short-run objectives should be two. The first is to refine the harvesting model by adding drying and storage facilities and by adjusting specific criteria. The most important criteria concern when to start harvest and how to handle the corn not harvested during the harvesting period. The second objective should be to add the other subsystem necessary to complete the corn production system. These subsystems include tillage, planting, and growing. The longer-run objective should be to extend the simulation to other crops.

The analysis of results from the replacement routine indicate a potential for a dynamic programming replacement routine of this type. In order to conform more with the real world, the routine should be adjusted to include the alternative of trading for a used machine. At this point the routine could be used to evaluate individual farm decisions by adding an appropriate matrix generator. A final extension could be to consider replacement of additional item, such as buildings, dairy cattle and/or livestock.

One last implication that is not limited to studies of this type is that researchers must be cognizant of the time period they are considering. In this study replacement decisions had to be separated from the other decisions to insure that the necessary long-run considerations would be made.

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APPENDICES

APPENDIX A

INPUT VALUES FOR CORN HARVEST SIMULATOR

APPENDIX A

INPUT VALUES FOR CORN HARVEST SIMULATOR

Appendix Table A. 1. Simulation Input Data

The following values are used as exogenous coefficients for the corn harvest simulator:

1. Coefficients for the combines.

New Cost

two-row	$12,000
four-row:	$16,000

Type of depreciation

Straight line with 20 per cent additional first year

Years to be depreciated over: eight

Salvage value: 10 per cent

Fuel cost:

two-row:	$1.775 per hour
four-row:	$3.50 per hour

Width:

two-row:	2 rows
four row:	4 rows

Harvester row spacing: 40 inches

Hours used per day: eight

Appendix Table A. 1 (cont'd.)

Efficiency of operator:

two-row: 1.0

four-row: 0.9

Repair function:

$$ARC = NC\ [(-.0197X_1 + .0087X_1^2 - .00053X_1^3,) + 1.02 + .00025X_2)]$$

ARC = annual repair cost

NC = new cost for the machine

X_1 = age of machine

X_2 = hours of annual use

2. Fixed coefficients

Hired wage rate:

First 600 hours:	$2.00 per hour.
Second 600 hours:	$2.25 per hour.
Third 600 hours:	$2.50 per hour.
Fourth 600 hours:	$2.75 per hour.
All in excess of 2400:	$3.00 per hour.

Tax rate: 20 per cent

Interest rate: 7.5 per cent

Housing charge: .0075 x depreciated value

Insurance charge: .0075 x depreciated value

Drying charge: $.01 per point to .155

Hauling charge: $ .06 per bushel (wet)

Land value: $600.00 per acre

Hours of operator's labor available: 320

Charge for operator's labor: $960.00

Appendix Table A. 1 (cont'd.)

3. State of system on October 1

Grain moisture content

First year:	0.367
Second year:	0.409
Third year:	0.278

Potential yield

First year:	150 bu.
Second year:	100 bu.
Third year:	125 bu.

4. Date of physiological death

First year:	10/30
Second year:	11/06
Third year:	10/11

5. Prices

Dates	1st year	2nd year	3rd year
10/15 - 10/21	1.22	1.08	0.87
10/22 - 10/28	1.22	1.07	0.87
10/29 - 11/4	1.22	1.06	0.92
11/5 - 11/11	1.22	1.05	0.95
11/12 - 11/18	1.22	1.04	0.96
11/19 - 11/25	1.23	1.05	0.97
11/26 - 12/02	1.24	1.06	0.98
12/31	1.25	1.07	1.02

APPENDIX B

SUPPORTING DATA ON THE EFFECT OF THE SELECTED VARIABLES ON THE HARVESTING PERIOD

Appendix Table B. 1. Income and Expense Figures for Each of the Three Years for a Two-Row and a

Appendix Table B. 1. Income and Expense Figures for Each of the Three Years for a Two-Row and a Four-Row Combine Using Base Values with a 300 Acre Enterprise

Income or expense	1st year		2nd year		3rd year		Average	
	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
Total receipts	51,329	51,701	21,664	24,957	32,198	31,360	35,064	35,999
Machinery expense[a]	3,154	3,761	3,080	3,661	3,114	3,733	3,116	3,718
Total cash expense[a]	11,220	12,111	7,310	7,799	8,285	8,766	8,940	9,559
Total expense[a]	27,723	29,295	23,726	24,869	24,616	25,721	25,355	26,628
Net cash income[a]	40,109	39,590	14,351	17,158	10,413	22,592	26,125	26,447
Management income[a]	23,584	22,405	-2,066	89	7,583	5,639	9,679	9,378
Net cash income[b]	26,583	26,090	851	3,386	10,413	9,092	12,625	12,947
Management income[b]	10,084	8,905	-15,566	-13,411	-5,917	-7,861	-3,791	-4,122
Acres harvested	294	300	105	186	300	300	233	262
Date harvest completed[c]	--	11/14	--	--	11/12	10/30	--	--
Hours combine used	198	109	195	107	188	104	194	107

[a]From harvesting only.

[b]Includes all expenses $45.00 per acre prior to October 1.

[c]When completed by December 1.

Appendix Table B. 2. Income and Expense Figures for Each of the Three Years for a Two-Row and a Four-Row Combine Using Base Values with a 400 Acre Enterprise

Income or expense	1st year		2nd year		3rd year		Average	
	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
Total receipts	61,383	68,935	27,417	30,835	43,569	42,302	44,123	47,357
Machinery expense[a]	3,496	4,037	3,399	3,939	3,420	3,995	3,438	3,992
Total cash expense[a]	13,546	13,553	9,433	9,900	10,731	11,181	11,236	12,211
Total expense[a]	34,549	37,238	30,350	31,469	31,561	32,633	32,152	33,780
Net cash income[a]	47,837	53,381	17,984	20,935	32,837	31,123	32,887	35,147
Management income[a]	26,834	31,697	-2,932	-634	12,007	9,669	11,970	13,578
Net cash income[b]	29,837	35,381	-15	3,935	14,867	13,123	14,887	17,147
Management income[b]	8,834	13,697	-20,932	-18,634	-5,993	-8,331	-6,030	-4,422
Acres harvested	332	400	104	188	400	400	279	329
Date harvest completed[c]	--	11/21	--	--	11/27	11/04	--	--
Hours combine used	269	146	262	144	252	138	261	143

[a]From harvesting only.

[b]Includes all expenses $45.00 per acre prior to October 1.

[c]When completed by December 1.

Appendix Table B. 3. Income and Expense Figures for Each of the Three Years for a Two-Row and a

Appendix Table B. 3. Income and Expense Figures for Each of the Three Years for a Two-Row and a Four-Row Combine Using Base Values with a 1000 Acre Enterprise

Income or expense	1st year		2nd year		3rd year		Average	
	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
Total receipts	123,128	139,357	62,439	65,690	85,543	98,278	90,370	101,108
Machinery expense[a]	5,533	5,811	5,312	5,608	5,388	5,656	5,410	5,691
Total cash expense[a]	28,480	30,600	22,947	22,601	23,138	24,294	24,854	25,831
Total expense[a]	76,484	79,285	70,864	71,270	70,968	72,747	72,771	74,400
Net cash income[a]	94,648	108,756	39,492	43,088	62,405	73,985	65,516	75,277
Management income[a]	46,645	60,072	-8,425	-5,481	14,584	25,531	17,599	26,708
Net cash income[b]	49,648	63,756	-5,508	-1,912	17,405	28,985	20,516	30,277
Management income[b]	1,645	15,072	-53,425	-50,481	-30,426	-19,469	-27,401	-18,292
Acres harvested	300	530	110	190	410	730	273	483
Date harvest completed[c]	--	--	--	--	--	--	--	--
Hours combine used	696	382	663	366	664	360	674	369

[a]From harvesting only.

[b]Includes all expenses. $45.00 per acre prior to October 1.

[c]When completed by December 1.

Appendix Table B. 4. Average Incomes from 300 Acres of Corn Using Alternative Loss Criteria for the Acres not Harvested Before December 1 for a Two-Row and Four-Row Combine

Penalty	Acres harvested		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
20%[a]	234	261	27,243	27,065	13,743	13,565	10,826	9,996	-2,674	-3,504
40%[a]	234	261	26,125	26,447	12,625	12,947	9,709	9,378	-3,791	-4,122
Sliding[b]	234	261	26,391	26,957	12,788	13,457	9,971	9,892	-3,529	-3,608
Sliding #2[c]	234	261	25,542	26,671	12,042	13,171	9,125	9,602	-4,375	-3,978

[a]20 and 40 per cent respectively of the corn that could be harvested December 31 is lost due to the possibility that the corn can never be harvested.

[b]5 per cent is lost from the first section not harvested by December 1 with an additional 1 per cent being lost for each additional section not harvested. A section is 1/100 of the total acreage.

[c]5 per cent is lost from the first acre not harvested by December 1 with an additional 0.5 per cent being lost on each succeeding acre not harvested.

Appendix Table B. 5. Average Incomes from 400 Acres of Corn Using Alternative Loss Criteria for

Appendix Table B. 5. Average Incomes from 400 Acres of Corn Using Alternative Loss Criteria for the Acres not Harvested Before December 1 for a Two-Row and Four-Row Combine

Penalty	Acres harvested		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
20%[a]	264	328	35,584	36,297	17,584	18,297	14,667	14,727	-3,333	-3,273
40%[a]	264	328	32,887	35,147	14,887	17,147	11,970	13,578	-6,030	-4,022
Sliding[b]	264	328	33,967	35,665	15,967	17,665	13,050	14,095	-4,950	-3,905
Sliding #2[c]	264	328	31,027	34,196	13,027	16,196	10,144	12,627	-7,856	-5,373

[a]20 and 40 per cent respectively of the corn that could be harvested December 31 is lost due to the possibility that the corn can never be harvested.

[b]5 per cent is lost from the first section not harvested by December 1 with an additional one per cent being lost for each additional section not harvested. A section is 1/100 of the total acreage.

[c]5 per cent is lost from the first acre not harvested by December 1 with an additional 0.5 per cent being lost on each succeeding acre not harvested.

Appendix Table B. 6. Average Incomes from 1000 Acres of Corn Using Alternative Loss Criteria for

Appendix Table B. 6. Average Incomes from 1000 Acres of Corn Using Alternative Loss Criteria for the Acres not Harvested Before December 1 for a Two-Row and Four-Row Combine

Penalty	Acres harvested		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
20%[a]	270	480	81,493	86,267	36,493	41,267	33,580	37,716	-11,422	-7,284
40%[a]	270	480	65,515	75,276	20,515	30,276	17,600	26,708	-27,401	-18,292
Sliding[b]	270	480	64,743	79,080	19,743	34,080	16,826	30,511	-28,174	-14,489
Sliding #2[c]	270	480	28,242	52,911	-16,758	7,911	-19,675	4,342	-64,675	-40,658

[a] 20 and 40 per cent respectively of the corn that could be harvested December 31 is lost due to the possibility that the corn can never be harvested.

[b] 5 per cent is lost from the first section not harvested by December 1 with an additional one per cent being lost for each additional section not harvested. A section is 1/100 of the total acreage.

[c] 5 per cent is lost from the first acre not harvested by December 1 with an additional 0.5 per cent being lost on each succeeding acre not harvested.

Appendix Table B. 7. Three Year Averages of Acres Harvested and Income from Different Sizes of Enterprise with a 20 Per Cent Loss on the Corn not Harvested by December 1

Acres	Harvested acres		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
200	168	194	17,969	18,033	8,969	9,033	6,052	5,464	-2,948	-3,536
300	234	261	27,243	27,065	13,743	13,565	10,826	9,980	-2,674	-3,520
400	264	328	35,584	36,297	17,584	18,297	14,667	14,727	-3,333	-3,273
500	270	395	43,407	45,694	20,884	23,194	18,883	19,624	-3,617	-2,876
1000	270	480	81,493	86,267	36,493	41,267	33,580	37,716	-11,422	-7,284

[a]Harvested acres means the average acres harvested prior to December 1.

Appendix Table B. 8. Three Year Averages of Acres Harvested and Income Received from Different Sizes of Enterprise with an Increasing Loss Function on the Corn not Harvested by December 1[a]

Acres	Harvested acres		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
200	168	194	17,748	18,082	8,748	9,082	5,830	5,513	-3,170	-3,487
300	234	261	26,388	26,957	12,888	13,457	9,971	9,887	-3,529	-3,613
400	264	378	33,967	35,665	15,967	17,665	13,050	14,095	-4,950	-3,905
500	270	395	40,517	44,327	18,017	21,827	15,103	18,258	-7,397	-4,242
1000	270	480	64,743	79,080	19,743	34,080	21,270	30,511	-23,730	-14,489

[a]5 per cent loss for the first section not harvested before December 1, 6 per cent for the second, 7 per cent for the third section, etc. A section is 1/100 of the total acres.

Appendix Table B. 9. Three Year Averages of Acres Harvested and Income Received from Different Sizes of Enterprise with a Second Increasing Loss Function on the Corn not Harvested by December 1[a]

Acres	Harvested acres		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
200	168	194	17,748	18,082	8,748	9,082	5,830	5,513	-3,170	-3,487
300	234	261	25,542	26,671	11,962	13,171	9,125	9,602	-4,375	-3,903
400	264	378	31,027	34,196	13,027	16,196	10,144	12,627	-7,856	-5,373
500	270	395	33,549	41,371	11,049	18,871	8,132	15,302	-14,368	-7,198
1000	270	480	28,242	52,911	-16,758	7,911	-19,675	4,342	-64,675	-40,658

[a]5 per cent loss for the first acre, .5 per cent additional for each additional acre not harvested by December 31. Maximum 100 per cent.

Appendix Table B. 10. The Effect on Average Acres Harvested and Income Received of Different Sizes of Corn Enterprises with a Ten Hour Work Day for a Two-Row and a Four-Row Combine

	Harvested acres		Net cash income from harvesting		Net cash income		Management income from harvesting[a]		Management income[a]	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
200	176	200	17,565	17,980	8,565	8,980	5,648	5,408	-3,352	-3,592
300	243	279	26,198	26,742	12,698	13,242	9,781	9,673	-3,719	-3,827
400	300	344	34,433	35,294	16,433	17,294	13,517	13,725	-4,685	-4,275
500	330	410	41,151	44,011	18,651	21,511	14,784	17,942	-7,716	-4,558
1000	340	600	68,205	80,147	23,205	35,147	20,288	31,578	-24,712	-13,422

[a]Includes $45.00 per acre to cover costs prior to harvest.

Appendix Table B. 11. The Effect on Average Acres Harvested and Income Received of Different Sizes of Corn Enterprises with a Twelve Hour Work Day for a Two-Row and a Four-Row Combine

	Harvested acres		Net cash income from harvesting		Net cash income		Management income from harvesting[a]		Management income[a]	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
200	184	200	17,725	17,839	8,725	8,839	5,808	5,270	-3,192	-3,730
300	252	291	26,289	27,074	12,789	13,574	9,872	10,000	-3,628	-3,500
400	320	360	35,052	35,544	17,052	17,544	14,132	13,975	-3,868	-4,025
500	365	425	42,651	44,168	20,151	21,668	17,234	18,099	-5,266	-4,401
1000	400	690	70,993	83,952	25,993	38,952	23,076	35,382	-21,924	-9,618

[a]Includes $45.00 per acre to cover cost prior to harvest.

Appendix Table B. 12. The Effect on Average Acres Harvested and Income Received of Different Sizes of Corn Enterprises with a Fourteen Hour Day for a Two-Row and a Four-Row Combine

	Harvested acres		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
200	194	200	17,935	17,716	8,935	8,716	6,018	5,148	-2,982	-3,852
300	261	300	26,413	27,201	12,915	13,701	9,996	10,131	-3,502	-3,369
400	328	376	35,068	35,890	17,068	17,890	14,151	14,321	-3,849	-3,679
500	395	440	43,915	44,259	21,415	21,859	18,498	18,290	-4,002	-4,210
1000	400	690	70,993	83,952	25,993	38,932	23,076	23,127	-21,924	-9,618

Appendix Table B. 13. The Effect on Average Acres Harvested and Income Received of Different Lengths of Work Days on a 300 Acre Corn Enterprise When 40 Per Cent of the Corn not Harvested During the Harvesting Season is Lost for a Two-Row and a Four-Row Combine

Hours[a]	Harvested acres		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
8	234	261	26,025	26,447	12,625	12,947	9,709	9,378	-3,791	-4,122
10	243	279	26,198	26,742	12,698	13,242	9,781	9,673	-3,719	-3,827
12	252	291	26,289	27,074	12,789	13,574	9,892	10,000	-3,628	-3,500
14	261	300	26,413	27,201	12,915	13,701	9,996	10,131	-3,502	-3,369

[a]Hourly labor cost remain constant as the hours worked increase.

Appendix Table B. 14. The Effect on Average Acres Harvested and Income Received of Different Lengths of Work Days on a 400 Acre Corn Enterprise when 40 Per Cent of the Corn not Harvested During the Harvesting Season is Lost for a Two-Row and a Four-Row Combine

Hours	Acres harvested		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
8	264	328	32,887	35,147	14,887	17,147	11,970	13,578	-6,030	-4,422
10	300	344	34,433	35,294	16,433	17,294	13,517	13,725	-4,685	-4,275
12	320	360	35,052	35,544	17,052	17,544	13,932	13,975	-3,868	-4,025
14	328	376	35,068	35,890	17,068	17,890	14,151	14,321	-3,849	-3,679

Appendix Table B. 15. The Effect on Average Acres Harvested and Income Received of Different Lengths of Work Days on a 1000 Acre Corn Enterprise When 40 Per Cent of the Corn not Harvested During the Harvesting Season is Lost for a Two-Row and a Four-Row Combine

Hours	Acres harvested		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
8	270	480	65,515	75,276	20,515	30,276	17,599	26,708	-27,401	-18,292
10	340	600	61,005	80,147	23,205	35,147	20,288	31,578	-24,712	-13,422
12	400	690	70,993	83,952	25,993	38,952	23,076	35,382	-21,924	-9,418
14	480	750	74,062	86,718	29,062	41,718	26,168	38,150	-18,832	-6,850

Appendix Table B. 16. The Effect on Average Acres Harvested and Income Received of Different Lengths of Work Days on a 200 Acre Corn Enterprise When 20 Per Cent of the Corn not Harvested During the Harvesting Season is Lost for a Two-Row and a Four-Row Combine

Hours	Acres harvested		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
8	168	194	17,969	18,033	8,969	9,033	6,052	5,464	-2,948	-3,536
10	176	200	17,945	17,978	8,945	8,978	6,028	5,403	-2,972	-3,592
12	186	200	17,963	17,839	8,963	8,839	6,046	5,270	-2,954	-3,730
14	194	200	18,033	17,716	9,033	8,716	6,116	5,147	-2,884	-3,853

Appendix Table B. 17. The Effect on Average Acres Harvested and Income Received of Different Lengths of Work Days on a 500 Acre Corn Enterprise When 20 Per Cent of the Corn not Harvested During the Harvesting Season is Lost for a Two-Row and a Four-Row Combine

Hours	Acres harvested[a]		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
8	270	395	43,407	45,694	20,887	23,194	17,990	19,624	-3,617	-2,876
10	330	410	44,522	45,449	22,022	22,949	19,105	19,380	-3,395	-3,120
12	365	425	45,129	45,362	22,629	22,862	19,712	19,293	-2,788	-3,207
14	395	440	45,623	45,308	23,123	22,808	20,207	19,239	-2,293	-3,261

[a]Acres harvested prior to December 1.

Appendix Table B. 18. The Effect on Average Acres Harvest and Income Received of Different Lengths of Work Days on a 200 Acre Corn Enterprise When the Percentage of the Corn Lost When Harvest is not Completed During the Harvest Season Increases as the Number of Acres Increases[a]

Hours	Acres harvested[b]		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
8	168	194	17,748	18,082	8,748	9,282	5,830	5,513	-3,170	-3,487
10	176	200	17,907	17,978	8,907	8,978	5,990	5,408	-3,010	-3,592
12	186	200	18,017	17,839	9,017	8,839	6,100	5,270	-2,900	-3,720
14	194	200	18,086	17,716	9,086	8,716	6,170	5,147	-2,830	-3,853

[a] 5 per cent for the first acre, 5.5 per cent for the second acre, etc.

[b] Acres harvested prior to December 1.

Appendix Table B. 19. The Effect on Average Acres Harvested and Income Received of Different Lengths of Work Days on a 500 Acre Corn Enterprise When the Percentage of the Corn Lost When Harvest is not Completed During the Harvest Season Increases as the Number of Acres Increases[a]

Hours	Acres harvested[b]		Net cash income from harvesting		Net cash income		Management income from harvesting		Management income	
	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
8	270	395	40,517	44,327	18,017	21,827	15,103	18,258	-7,397	-4,242
10	330	410	42,501	44,658	20,001	22,158	17,084	18,589	-5,416	-3,911
12	365	425	43,690	44,974	21,139	22,474	18,222	18,904	-4,278	-3,596
14	395	440	44,257	42,213	21,757	22,713	18,840	18,944	-3,660	-3,556

[a]5 per cent loss for the first section, 6 per cent loss for the second, etc. A section is 1/100 of the total acreage or 5 acres.

[b]Acres harvested prior to December 1.

Appendix Table B. 20. Three Year Average Income Received Using Each Combine on 300 Acres with Alternative Criteria Concerning the Grain Moisture Content

Criterion[d]	Date harvest started[a]			Tractable days after harvest started[b]			Acres harvested during harvest period (ave.)		Net cash income[c] (ave.)		Management income (ave.)	
	1st year	2nd year	3rd year	1st year	2nd year	3rd year	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
.28	10/31	11/09	10/15	22	7	32	215	254	11,852	12,951	-4,565	-4,118
.30	10/28	11/08	10/15	24	8	32	233	262	12,625	12,947	-3,791	-4,122
.32	10/24	11/08	10/15	28	8	32	235	262	12,431	12,555	-3,986	-4,514
sliding[e]	10/29	11/08	10/16	23	8	31	229	262	12,537	13,159	-3,880	-3,910

[a]First day that the moisture criterion was net and the soil was tractable.

[b]Number of days after harvest started that the land was tractable.

[c]Includes the $45.00 per acre cost prior to harvest.

[d]Harvest is allowed when corn is drier than the criterion.

[e]Harvest could start if grain moisture content fell below .26 before October 21, .28 before October 28, .30 before November 4, .32 before November 11, .34 before November 18, .40 before November 25.

Appendix Table B. 21. Three Year Average Income Received Using Each Combine on 400 Acres with Alternative Criteria Concerning the Grain Moisture Content

Criterion[d]	Date harvest started[a]			Tractable days after harvest started[b]			Acres harvested during harvest period (ave.)		Net cash income[c] (ave.)		Management income (ave.)	
	1st year	2nd year	3rd year	1st year	2nd year	3rd year	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
.28	10/31	11/09	10/15	22	7	32	249	321	14,205	17,223	-6,712	-4,346
.30	10/28	11/08	10/15	24	8	32	279	329	14,887	17,147	-6,030	-4,422
.32	10/24	11/08	10/15	28	8	32	283	329	15,657	16,701	-5,259	-4,868
sliding[e]	10/29	11/08	10/16	23	8	31	260	329	14,742	17,389	-6,175	-4,180

[a]First day that the moisture criterion was net and the soil was tractable.

[b]Number of days after harvest started that the land was tractable.

[c]Includes the $45.00 per acre cost prior to harvest.

[d]Harvest is allowed when corn is drier than the criterion.

[e]Harvest could start if grain moisture content fell below .26 before October 21, .28 before October 28, .30 before November 4, .32 before November 11, .34 before November 18, .40 before November 25.

Appendix Table B. 22. Three Year Average Income Received Using Each Combine on 1000 Acres with Alternative Criteria Concerning the Grain Moisture Content

Criterion[d]	Date harvest started[a]			Tractable days after harvest started[b]			Acres harvested during harvest period (ave.)		Net cash income[c] (ave.)		Management income[c] (ave.)	
	1st year	2nd year	3rd year	1st year	2nd year	3rd year	2-row (acres)	4-row (acres)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
.28	10/31	10/09	10/15	22	8	32	253	443	19,714	28,608	-28,203	-19,965
.30	10/28	11/08	10/15	24	8	32	273	483	20,516	30,277	-27,401	-18,292
.32	10/24	11/08	10/15	28	8	32	290	507	21,252	31,249	-26,665	-17,320
sliding[e]	10/29	11/08	10/16	23	8	31	263	467	20,149	29,731	-27,768	-18,838

[a]First day that the moisture criterion was net and the soil was tractable.

[b]Number od days after harvest started that the land was tractable.

[c]Includes the $45.00 per acre cost prior to harvest.

[d]Harvest is allowed when corn is drier than the criterion.

[e]Harvest could start if grain moisture content fell below .26 before October 21, .28 before October 28, .30 before November 4, .32 before November 11, .34 before November 18, .40 before November 25.

APPENDIX C

SUPPORTING DATA ON RANKING OF VARIABLES

Appendix Table C. 1. The Effect of Changes in the Variables with a 200 Acre Enterprise in Each Year

Variables	1st year		2nd year		3rd year		Average	
	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
Loss[a]	0	0	1562	261	0	0	520	87
Size[b]	4673	4562	-5317	-5242	-321	-816	-322	-499
Hours[c]	-168	-162	876	440	-357	-183	117	95
Grain moisture[d]	-582	-803	209	326	0	0	-124	-159
Opportunity cost[e]	392	216	496	211	373	207	420	211
Additional rainfall[f]	-145	-128	-1	3	-160	-160	-102	-95
Temperature[g]	1556	1274	975	1149	264	505	932	976
Price[h]	1412	1413	745	903	1192	1192	1116	1169
Yield[i]	975	952	624	764	724	690	774	802

[a]Positive amount indicates the income is that much higher when 20 per cent is assumed to be lost.

[b]Positive amounts indicate income increases as the enterprise is expanded from 200 to 300 acres; negative figures indicate an income loss.

[c]Positive figures show an increase in income with increased hours, negative figures decreased income.

[d]This variable refers to changes in the criterion for maximum grain moisture before harvest can commence. Positive values indicate increased income when the maximum is increased so harvest can begin earlier; negative values indicate decreased income from increasing the maximum.

[e]This variable is the value of the combine operator's time. The figure represents the increased cost when this value increases.

[f]Positive figures indicate that income decreased with additional rainfall; negative values show increased income with additional rainfall.

[g]Indicates the increase in income as average temperature increases.

[h]Shows the increase in income with increased prices.

[i]Shows amount of increase in income with an increase in potential yield at beginning of harvesting period (cotober 1).

Appendix Table C. 2. The Effect of Changes in the Variables with a 500 Acre Corn Enterprise in Each Year

Variables[a]	1st year		2nd year		3rd year		Average	
	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)	2-row (dol.)	4-row (dol.)
Loss	6212	0	6429	5127	1866	0	4402	1709
Size	-1014	5110	-5311	-5401	-3623	-195	-3316	-162
Hours	3981	-710	839	1698	2919	-908	2580	8
Grain moisture	2075	-72	229	458	0	2	768	193
Opportunity cost	1022	548	983	545	960	422	988	505
Additional rainfall	3123	4187	0	0	926	-434	1350	1251
Temperature	4085	3650	2094	2087	195	434	2125	2057
Price	2915	3525	1561	1717	2735	2974	2404	2739
Yield	1918	2487	1383	1488	1688	1841	1662	1939

[a]See Table C. 1, page 191 for explanations of changes in the variables except the change in the variable size which is from 400 to 500 acres.

Appendix Table C. 3. Economic Ranking of Variables in Each Year--200 Acres

Rank	2-row Variable	2-row Change (dol.)	4-row Variable	4-row Change (dol.)
		First Year		
1	Size	4673	Size	4562
2	Temperature	1556	Price	1413
3	Price	1412	Temperature	1274
4	Yield	975	Yield	952
5	Grain moisture	-582	Grain moisture	-803
6	Opportunity cost	392	Opportunity cost	216
7	Hours	-168	Hours	-162
8	Rainfall	-145	Rainfall	-128
9	Loss	0	Loss	0
		Second Year		
1	Size	-5317	Size	-5242
2	Loss	1562	Temperature	1149
3	Temperature	975	Price	903
4	Hours	876	Yield	764
5	Price	745	Hours	440
6	Yield	624	Grain moisture	326
7	Opportunity cost	496	Loss	261
8	Grain moisture	209	Opportunity cost	211
9	Rainfall	-1	Rainfall	3

Appendix Table C. 3 (cont'd.)

Rank	2-row		4-row	
	Variable	Change (dol.)	Variable	Change (dol.)
		Third Year		
1	Price	1192	Price	1192
2	Yield	724	Size	-816
3	Opportunity cost	373	Yield	690
4	Hours	-357	Temperature	505
5	Size	321	Opportunity cost	207
6	Temperature	264	Hours	-183
7	Rainfall	-160	Rainfall	-160
8	Grain moisture	0	Loss	0
9	Loss	0	Grain moisture	0
		Average		
1	Price	1116	Price	1169
2	Temperature	932	Temperature	976
3	Yield	774	Yield	802
4	Loss	520	Size	-499
5	Opportunity cost	420	Opportunity cost	211
6	Size	-332	Grain moisture	-159
7	Hours	117	Hours	95
8	Grain moisture	-124	Rainfall	95
9	Rainfall	102	Loss	87

Appendix Table C. 4. Economic Ranking of Variables in Each Year--500 Acres

Rank	2-row Variable	2-row Change (dol.)	4-row Variable	4-row Change (dol.)
		First Year		
1	Loss	6212	Size	5110
2	Temperature	4085	Rain	4187
3	Hours	3981	Temperature	3650
4	Rainfall	3123	Price	3525
5	Price	2915	Yield	2487
6	Grain moisture	2075	Hours	-710
7	Yield	1914	Opportunity cost	548
8	Opportunity cost	1022	Grain moisture	-72
9	Size	-1014	Loss	0
		Second Year		
1	Loss	6429	Size	-5401
2	Size	-5311	Loss	5127
3	Temperature	2094	Temperature	2087
4	Price	1561	Price	1717
5	Yield	1383	Hours	1698
6	Opportunity cost	983	Yield	1488
7	Hours	839	Opportunity cost	545
8	Grain moisture	229	Grain moisture	458
9	Rainfall	0	Rainfall	0

Appendix Table C. 4 (cont'd.)

Rank	2-row		4-row	
	Variable	Change (dol.)	Variable	Change (dol.)
		Third Year		
1	Size	-3623	Price	2974
2	Price	2735	Yield	1841
3	Hours	2919	Hours	-908
4	Loss	1866	Temperature	434
5	Yield	1688	Rainfall	-434
6	Opportunity cost	960	Opportunity cost	422
7	Rainfall	926	Size	-195
8	Temperature	195	Grain moisture	2
9	Grain moisture	0	Loss	0
		Average		
1	Loss	4402	Price	2739
2	Size	-3316	Temperature	2057
3	Hours	2580	Yield	1939
4	Price	2404	Loss	1709
5	Temperature	2125	Rainfall	1351
6	Yield	1662	Opportunity cost	505
7	Rainfall	1350	Grain moisture	193
8	Opportunity cost	988	Size	-162
9	Grain moisture	768	Hours	27

Appendix Table C. 5. Effect of Changes in the Variables With and Without Completion of Harvest--200 Acres[a]

Variable	2-row		4-row	
	Completed[b] (dol.)	Not completed[c] (dol.)	Completed[b] (dol.)	Not completed[c] (dol.)
Loss[d]	0	1562	0	261
Size[e]	2176	-5317	1874	-5424
Hours[f]	-262	876	-172	440
Grain moisture[g]	-191	209	-402	326
Opportunity cost[h]	382	496	211	211
Additional rainfall[i]	-152	0	-94	0
Temperature[j]	910	975	872	1149
Price[k]	1302	745	1158	903
Yield[l]	850	624	821	764

[a]Harvest completed means completed by NOvember 30. All corn not harvested by then is assumed to be harvested at December 31 conditions with a 40 per cent loss.

[b]This column contains figures from the first and the third year.

[c]This column contains figures from the second year.

[d]See Table C. 1, page 191, footnote one.

[e]See Table C. 1, page 191, footnote two.

[f]See Table C. 1, page 191, footnote three.

[g]See Table C. 1, page 191, footnote four.

[h]See Table C. 1, page 191, footnote five.

[i]See Table C. 1, page 191, footnote six.

[j]See Table C. 1, page 191, footnote seven.

[k]See Table C. 1, page 191, footnote eight.

[l]See Table C. 1, page 191, footnote nine.

Appendix Table C. 6. Effect of Change in the Variables With and Without Completion of Harvest--500 Acres[a]

Variable	2-row		4-row	
	Completed[b] (dol.)	Not completed[c] (dol.)	Completed[d] (dol.)	Not completed[e] (dol.)
Loss[f]	--	4836	0	5127
Size[g]	--	-3316	2458	-5401
Hours[h]	--	2580	-809	1698
Grain moisture[i]	--	768	-35	458
Opportunity cost[j]	--	988	484	545
Additional rainfall[k]	--	1350	-434	2094
Temperature[l]	--	2125	2042	2087
Price[m]	--	2404	3250	1717
Yield[n]	--	1662	2164	1488

[a]Harvest completed means completed by November 30. All corn not harvested by then is assumed to be harvested at December 31 conditions with a 40 per cent loss.

[b]Harvest is never completed with the two-row.

[c]This column contains figures from all three years.

[d]This column contains figures from the first and third year.

[e]This column contains figures from the second year.

[f]See Table C. 1, page 191, footnote one.

[g]See Table C. 1, page 191, footnote two.

[h]See Table C. 1, page 191, footnote three.

[i]See Table C. 1, page 191, footnote four.

[j]See Table C. 1, page 191, footnote five.

[k]See Table C. 1, page 191, footnote six.

[l]See Table C. 1, page 191, footnote seven.

[m]See Table C. 1, page 191, footnote eight.

[n]See Table C. 1, page 191, footnote nine.

Appendix Table C. 7. Economic Ranking of Variables Depending upon Completion of Harvest--200 Acres

Rank	Completed		Not completed	
	Variable	Change (dol.)	Variable	Change (dol.)
	Two-Row			
1	Size	2176	Size	-5317
2	Price	1302	Loss	1562
3	Temperature	910	Temperature	975
4	Yield	850	Hours	876
5	Opportunity cost	382	Price	745
6	Hours	-262	Yield	624
7	Grain moisture	-191	Opportunity cost	496
8	Rainfall	-152	Grain moisture	209
9	Loss	0	Rainfall	0
	Four-Row			
1	Size	1874	Size	-5424
2	Price	1158	Temperature	1149
3	Temperature	872	Price	903
4	Yield	821	Yield	764
5	Grain moisture	-402	Hours	440
6	Opportunity cost	211	Grain moisture	326
7	Hours	-172	Loss	261
8	Rainfall	-94	Opportunity cost	211
9	Loss	0	Rainfall	0

Appendix Table C. 8. Economic Ranking of Variables Depending upon Completion of Harvest--500 Acres

Rank	Completed		Not completed	
	Variable	Change (dol.)	Variable	Change (dol.)
		Two-Row		
1			Loss	4836
2			Size	-3316
3			Hours	2580
4			Price	2404
5			Temperature	2125
6			Yield	1662
7			Rainfall	1350
8			Opportunity cost	988
9			Grain moisture	768
		Four-Row		
1	Price	3250	Loss	5127
2	Size	2458	Size	-5401
3	Yield	2164	Rainfall	2094
4	Temperature	2042	Temperature	2087
5	Hours	-809	Price	1717
6	Opportunity cost	484	Hours	1698
7	Rainfall	-434	Yield	1488
8	Grain moisture	-35	Opportunity cost	545
9	Loss	0	Grain moisture	458

Appendix Table C. 9. Effect of Changes in Variables on the Choice of a Combine with a 200 Acre Corn Enterprise

Variable	1st year[a] (dol.)	2nd year[a] (dol.)	3rd year[a] (dol.)	Average[a] (dol.)
Loss[b]	0	1301	0	434
Size[c]	110	74	495	226
Hours[d]	38	-436	-175	-191
Grain moisture[e]	218	110	0	109
Opportunity cost[f]	176	172	166	171
Rainfall[g]	-17	0	0	-6
Temperature[h]	-282	174	241	44
Price[i]	1	158	0	53
Yield[j]	-23	140	-34	28

[a]The values represent the change for a 4-row combine minus the change for a 2-row combine.

[b]As loss increases from 20 per cent to 40 per cent the 4-row becomes the given amount more profitable than the 2-row.

[c]200 to 300 acre increase.

[d]8 hour day increases to 10 hours day. Negative figure indicates 2-row increased in relative profitability with the increased hours.

[e]2 per cent increase in maximum grain moisture.

[f]$3.00 increase in labor cost.

[g]Reduction of 1" rainfall. Negative figures indicate 2-row increased in relative profitability with increased rainfall.

[h]85 per cent increase in average temperature.

[i]$.05 increase in price.

[j]5 bushel increase in potential yield. Negative figures indicate 2-row increased in relative profitability.

Appendix Table C. 10. Effect of Changes in Variables on the Choice of a Combine with a 500 Acre Corn Enterprise

Variable	1st year[a] (dol.)	2nd year[a] (dol.)	3rd year[a] (dol.)	Average[a] (dol.)
Loss[b]	6512	1302	1866	3327
Size[c]	6124	-90	3428	3154
Hours[d]	-4691	829	-3827	-2563
Grain moisture[e]	-1807	228	0	-526
Opportunity cost[f]	-474	439	438	450
Rainfall[g]	-1064	0	-1360	-808
Temperature[h]	-435	7	239	-63
Price[i]	610	156	239	335
Yield[j]	573	105	153	277

[a]The values represent the change for a 4-row combine minus the change for a 2-row combine.

[b]As loss increases from 20 per cent to 40 per cent the 4-row becomes the given amount more profitable than the 2-row.

[c]400 to 500 acre increase.

[d]8 hour day increases to 10 hour day. Negative figure indicates 2-row increased in relative profitability with the increased hours.

[e]2 per cent increase in maximum grain moisture.

[f]$3.00 increase in labor cost.

[g]Reduction of 1" rainfall. Negative figures indicate 2-row increased in relative profitability with increased rainfall.

[h]85 per cent increase in average temperature.

[i]$.05 increase in price.

[j]5 bushel increase in potential yield. Negative figures indicate 2-row increased in relative profitability.

Appendix Table C. 11. Ranking of Variables According to Their Effect on the Choice Between the Two Combines

Rank	200 acres		500 acres	
	Variable	Change (dol.)	Variable	Change (dol.)
	First Year			
1	Temperature	-282	Loss	6512
2	Grain moisture	218	Size	6124
3	Opportunity cost	176	Hours	-4691
4	Size	110	Grain moisture	-1807
5	Hours	38	Rainfall	-1064
6	Yield	-23	Price	610
7	Rainfall	-17	Yield	573
8	Price	1	Opportunity cost	474
9	Loss	0	Temperature	-435
	Second Year			
1	Loss	1301	Loss	1302
2	Hours	-463	Hours	829
3	Temperature	174	Opportunity cost	439
4	Opportunity cost	172	Grain moisture	228
5	Price	158	Price	156
6	Yield	140	Yield	105
7	Grain moisture	110	Size	-90
8	Size	74	Temperature	7
9	Rainfall	0	Rainfall	0

Appendix Table C. 11 (cont'd.)

Rank	200 acres		500 acres	
	Variable	Change (dol.)	Variable	Change (dol.)
	Third Year			
1	Size	495	Hours	-3827
2	Temperature	241	Size	3428
3	Hours	-175	Loss	1866
4	Opportunity cost	166	Rainfall	-1360
5	Yield	-34	Opportunity cost	438
6	Rainfall	0	Temperature	239
7	Price	0	Price	239
8	Grain moisture	0	Yield	153
9	Loss	0	Grain moisture	0
	Average			
1	Loss	434	Loss	3227
2	Size	226	Size	3154
3	Hours	-191	Hours	-2563
4	Opportunity cost	171	Rainfall	-808
5	Grain moisture	109	Grain moisture	-526
6	Price	53	Opportunity cost	450
7	Temperature	44	Price	335
8	Yield	28	Yield	277
9	Rainfall	-6	Temperature	-63

Appendix Table C. 12. Ranking of the Effect of Changing Variables on the Choice of Machine by Categories Concerning Completion of Harvest[a]

Rank	Variable	Change (dol.)
Both Combines Complete Harvest		
1	Size	302
2	Opportunity cost	171
3	Grain moisture	109
4	Hours	68
5	Yield	28
6	Temperature	20
7	Rainfall	-8
8	Price	0
9	Loss	0
Only 4-Row Completes Harvest		
1	Size	4776
2	Hours	-4259
3	Loss	4189
4	Rainfall	1212
5	Grain moisture	-904
6	Opportunity cost	456
7	Price	424
8	Yield	363
9	Temperature	-98

Appendix Table C. 12 (cont'd.)

Rank	Variable	Change (dol.)
Neither Combine Completes Harvest		
1	Loss	1302
2	Opportunity cost	305
3	Hours	198
4	Grain moisture	169
5	Price	157
6	Yield	122
7	Temperature	90
8	Size	-8
9	Rainfall	0

[a]Positive numbers indicate the four-row combine's relative income improved with the changes outlined in Table

APPENDIX D

SUPPORTING DATA ON REPLACEMENT ROUTINE

APPENDIX D

SUPPORTING DATA ON REPLACEMENT ROUTINE

Appendix Table D. 1. Additional Input and Output Using Armstrong Data with 200 Hours of Use

State	Cost to keep	Cost to trade	Interest rate	Optimum policy	Ave. cost or discounted present value
1	734	5862	0.00	Keep 6 years	2359
2	899	6306	.05	Keep 6 years	56096
3	1158	6750	.075	Keep 7 years	36886
4	1473	7194	.10	Keep 7 years	27043
5	1806	7638	.125	Keep 7 years	21456
6	2119	8082	.20	Keep 7 years	14134
7	2374	8526			

Appendix Table D. 2. Additional Output Using Bower's Data for 200 Hours

State	Cost to keep	Cost to trade	Interest rate	Optimum policy	Ave. cost or discounted present value
1	228	5244	0.00	Keep 5 years	2090
2	480	5952	.05	Keep 5 years	46491
3	816	6600	.075	Keep 6 years	32978
4	1248	7176	.10	Keep 6 years	26003
5	1784	7680	.125	Keep 6 years	21850
6	2376	8148	.20	Keep 6 years	15,730
7	3072	8556			