

AGRONOMIC, ENGINEERING, AND METEOROLOGICAL DATA REQUIRED IN AN ECONOMIC MODEL OF FARM MACHINERY SELECTION

R.L. Batterham*

School of Agricultural Economics and Extension Education
Ontario Agricultural College
University of Guelph
Guelph, Ontario N1G 2W1

D.M. Brown

Land Resource Science Department
Agrometeorology
Ontario Agricultural College
University of Guelph
Guelph, Ontario N1G 2W1

P. Van Die**

School of Engineering
Ontario Agricultural College
University of Guelph
Guelph, Ontario N1G 2W1

INTRODUCTION

Computerized models are being used to assist farmers' decisions with respect to machinery selection and use.^a In particular, linear programming and simulation models have been developed to determine the possible actions that might be taken by the farmer. Most of the models evaluate varying alternatives that contribute to the economic and other objectives of the farmer, by taking into consideration the physical requirements set by the engineering characteristics of the machines, and by the agronomic characteristics of the crops to be grown.

No model can give better results than the data used in it. Therefore it is important that the agronomic, engineering, and meteorological requirements of an economic model of farm machinery selection be refined. Much of the data required can only be gathered as a result of interdisciplinary research between vari-

ous combinations of engineers, economists, meteorologists, and soil and crop scientists, using a systems approach.

Risk in the outcome of alternative actions is an important element in farmer decisions making. The uncontrollable nature of the weather makes it necessary to use probabilities to determine the risks associated with each action a farmer might consider. To determine the suitability of alternative farm machinery systems for a crop production program in a given climatic region, it is desirable to simulate the outcome of the crop production program using weather data recorded in past years for each machine system. Thus, it is important that the data, collected as a result of this research work, be reported in the form of probability distributions (or left in the form of frequencies) rather than be summarized into averages.

The objectives of the paper are:

- (1) to summarize an economic model of farm machinery investment;
- (2) to examine the data required for the model, particularly data concerned with the cost of untimely field operations (which are considered to be part of machine operating costs);
- (3) to determine which of the data are readily available in Canada, and to indicate those data not available at all, or not available in a form suitable for use in the model;
- (4) to indicate research required to derive and interpret data in the latter categories above.

THE ECONOMIC MODEL

Economic models for the selection of individual farm machines, and systems of

farm machines, have been outlined by Batterham.^b These models are based on a generally accepted economic theory of investment that has been rigorously stated by Hirshliefer (8). The model for the selection of a single farm machine uses a capital budgeting technique. In addition to the capital budgeting technique the model for selection of a machine system uses an optimizing algorithm, linear programming.

In both models, the farm machine, or machine system, is considered to be a "plant" that produces a "product" in the form of required crop operations. The economic objective in the models is to maximize the net present value of the investment in a machine (or system), subject to the constraint that the machine (or system) be capable of performing the crop operations required. The net present value of an investment might be best explained as the profit the investment returns over a period of time.

The net present value of an investment in farm machinery may be calculated using a series of steps. First, and most importantly, the cash flows generated by the investment must be estimated for each year. Secondly, the cash flows are discounted by a present value factor calculated as:

$$PVF = 1/(1+r)^n \dots \dots \dots (1)$$

where

^b Batterham, R.L. 1973. Analysis of machinery investment and financing using capital budgeting. School of Agricultural Economics and Extension Education, University of Guelph, 1973 (in progress); and Batterham, R.L. 1973. A systems approach to financing farm machinery investment. School of Agricultural Economics and Extension Education, University of Guelph, 1973 (in progress), respectively.

^a Several computerized models for selecting and using farm machinery are in use or are being developed in Ontario. OMAF has several programs as part of its COMSOLVE package. Van Die and Batterham have recently developed corn harvest machine selection programs at the University of Guelph. CANFARM is also developing farm machinery selection and replacement programs.

* Present address: Department of Agricultural Economics, University of Sydney, Sydney, New South Wales, Australia.

** Present address: CANFARM Data Systems, Agriculture Canada, Guelph, Ontario.

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PVF = the present value factor;
 r = the discount rate;
 n = the year in which the cash flow will occur.

Thirdly, the discounted cash flows are summed over the number of years being analyzed: the "planning horizon." The net present value (NPV) is calculated as:

$$NPV = \sum_{n=1}^t A_n \cdot PVF \dots \dots \dots (2)$$

$$= \sum_{n=1}^t A_n / (1+r)^n$$

where

NPV = the net present value of the investment;
 A_n = the cash flow in year n;
 t = the length of the planning horizon in years.

For examples of the discounting process see Batterham.^c

The discount rate *r* reflects the "time preference" the decision maker holds between present and future income, and might be thought of as the opportunity cost of capital. The opportunity cost of capital may be approximated by the interest rate paid on money borrowed to finance the purchase of the machine(s).

Risk can be incorporated into the economic model by considering the variance of possible outcomes expressed in net present value terms (see Van Horne 26). The expected net present value is:

$$E(NPV) = \sum_{n=1}^t \bar{A}_n / (1+r)^n \dots \dots \dots (3)$$

where

\bar{A}_n = the expected cash flow in year *n*.

The variance of net present value is defined as:

$$\sigma_{NPV}^2 = \sum_{n=1}^t \sigma_n^2 / (1+r)^{2n} \dots \dots \dots (4)$$

where

σ_n^2 = the variance of cash flows in year *n*.

The formula for variance holds so long as cash flows are serially independent between years.

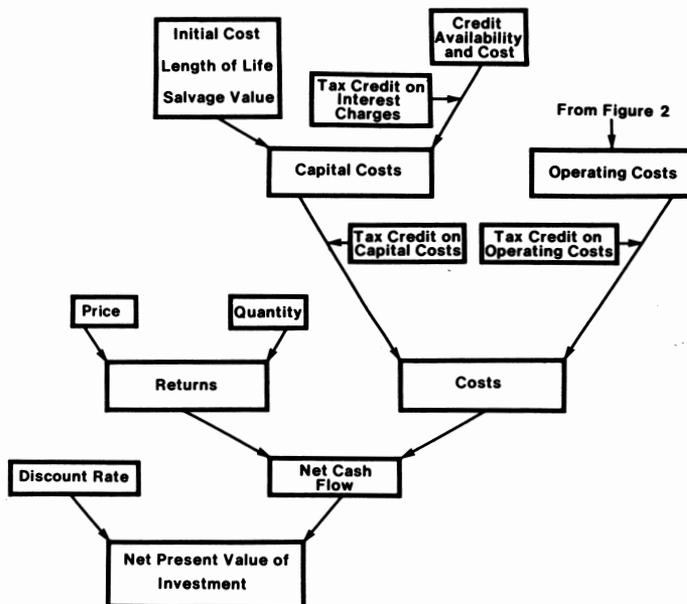


Figure 1. An economic model for the selection of farm machinery.

The decision maker (farmer) may now choose machines based on his preference for expected net present value and the variance of net present value. An economic theory of decision making called "Bernoullian decision theory" (see Dillon 6) has recently emerged to assist in making these trade-off decisions.

For these models to be applied in assisting farmers to select farm machinery, a variety of data is required.

DATA REQUIREMENTS

Economic Data

The essential economic data required in the above model are the discount rate (which is not considered further in this paper) and the net cash flows (see Figure 1). The cash flows are usually calculated on a yearly basis. They include the initial capital cost of the investment and operating costs and returns of the investment over time.

The returns from investment in farm machines are quite difficult to assess because crops and livestock are produced using a variety of inputs. In a partial farm investment analysis, such as machinery selection, only those returns that change for different investment alternatives need to be considered. The difference in the returns from alternative farm machines that might be engaged in a particular crop operation will depend on the physical manner in which the operation is performed, and on the timeliness of the operation. It is possible to use whole farm analysis that explicitly considers all inputs to determine the change for differ-

ent investment alternatives, although it is usually more costly than partial farm analysis.

Capital costs depend on several factors. These include the initial cost of the machine (allowing for trade-ins, discounts, etc.), its economic life, its salvage value, tax credits available on the capital cost allowance for the machine and on various methods of financing the purchase of a machine.

The economic life of the machine depends on the physical life-span and on operating costs and returns. In particular it may be sensitive to the increasing frequency and severity of breakdowns over time. These may be costly in both time losses and repair costs. These data must come largely from engineering sources (see "Engineering Data").

Operating costs per acre are determined by real machine capacity and operating costs per unit of time (see Figure 2). Operating costs per hour are, in turn, determined by the costs of fuel, lubricants, labor, repairs and maintenance, etc., and by the time available to work at a field operation. The time available to work is influenced by the total period during which a field operation is technically feasible, the period during which labor is available, and by the time lost due to adverse crop and weather conditions and due to machine breakdown. A small machine may have a large operating cost attached to it, because it is unable to complete a field operation in a timely manner.

Losses due to Untimely Operations

Among the more important benefits of

^c Batterham, R.L. 1973. Analysis of farm machinery investment and financing using capital budgeting. School of Agricultural Economics and Extension Education, University of Guelph, 1973 (in progress).

an economic model for the selection of farm machinery is the consideration it gives to crop losses resulting from untimely machine operations (12, 21). Timeliness is more critical for some operations and crops than for others. The timing of the various crop operations may behave in a complex interacting manner. A 1-wk delay in the spring can shift an entire set of field operations so that the yield and quality at harvest are likely to be reduced due to a shortened growing season. For example, an oft quoted rule of thumb is that grain corn yields decrease about 1 bushel/acre per day when planting is delayed after May 10 in southwestern Ontario.

For an economic model, mathematical relationships representing the interaction between expected yield levels and the timing of each field operation are required. This is graphically illustrated in Figure 3, as any planting, spraying, cultivating, or harvesting done at less than optimum time reduces the yield potential. Such data are obtained from agronomic experiments conducted for several years. More ideally complete crop growth models might be used to simulate crop yields for the new higher yielding varieties and predicted timing of operations in individual years.

Agronomic Data

Crop yields and stages of development are the essential agronomic requirements for economic models. In general, crop yields are a function of the varieties grown and soil conditions as well as the weather and timeliness of field operations. Variety tests provide relative yield levels for available varieties of each species, but do not provide actual on-farm yields. Such yields have to be obtained from farm records. In addition, soil type and fertility influence yield and require consideration in production models. Many fertilizer trials have been conducted, but few have been related to soil type, weather, and the timing of crop operations. As a result much of the yield data collected in agronomic experiments cannot be used in economic models without some interpretation.

For prediction of crop development stages, heat units are used in Canada (3, 4) and growing degree-days in the United States (30). These systems were developed for indexing the maturity of corn hybrids for recommendation purposes and are not sufficiently accurate for prediction of development stages through the growing season. Systems comparable to the Biometeorological Time Scale for wheat (17) are needed for other crops to predict the time of occurrence of critical growth stages.

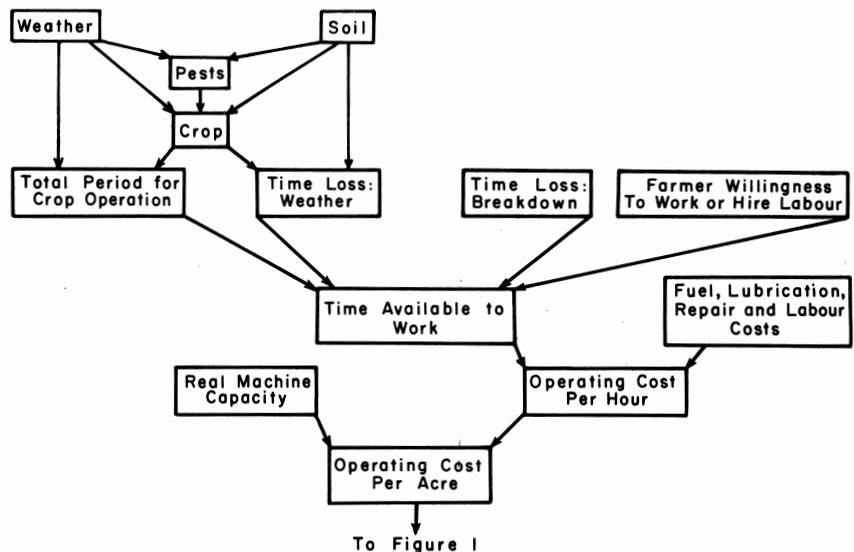


Figure 2. Factors that affect operating cost of a farm machine.

Agrometeorological Data

It is quite apparent that knowledge of expected weather and of the frequency of suitable workdays for the farm machinery system is a necessary requirement for economics decision-making in agriculture. Machinery investment decisions depend on information about the frequency of occurrence of some minimum available time for completion of a given operation (13, 18, 19, 20, 25).

Suitable operating conditions depend on the crop, the soil, and the weather. The number of field workdays in each week of the growing season is reported in the U.S. Weekly Weather and Crop Bulletin (29) for some states. This type of information is not reported for any locality in Canada. Thus, it is necessary to determine the frequency of occurrence of workdays from historical weather records.

Two methods have been used to determine the number of available workdays in each season. One method assumes that the ability to operate machinery is a function of the daily amounts of rainfall only, e.g., 0.25 inches of rain in 1 d prevents field work, but this is a criterion only suitable for some operations. The second method, and the one now most commonly used, assumes that the soil moisture has to be below a certain level before the soil is trafficable by farm machinery (18, 19, 20, 25).

Daily records of soil moisture content throughout the growing season are again practically nonexistent, making it necessary to estimate daily soil moisture content from weather records. Recorded precipitation and computed values of daily evapotranspiration can be used to

YIELD VS. TIMING OF OPERATION

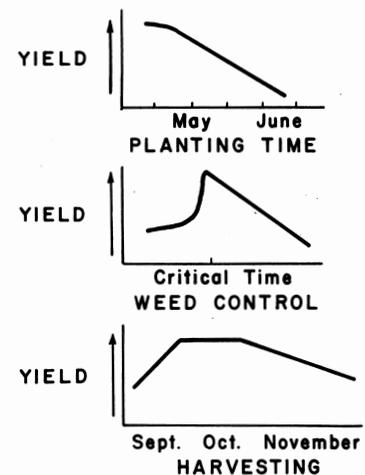


Figure 3. Effect of timing of operations on grain corn yields.

estimate soil moisture (1, 9). Problems still exist for this computation because percolation and runoff are not adequately accounted for in most prediction models. The most common method of computing daily potential evapotranspiration is the energy budget approach originated by Penman (15) but it is still not completely satisfactory after more than 20 yr of research. Further refinement of these models is needed to predict the frequency of occurrence of good workdays.

Phenological and soil moisture records have usually been recorded in connection with specific experiments. Very little attempt has been made to record crop phenological events and soil moisture on a routine basis. The one exception is the routine soil moisture observation program in fall and spring in the Prairie Provinces (23).

Simulation models for prediction of occurrence of certain plant disease outbreaks have been developed in recent years. Waggoner and Horsfall (27) developed a computer program known as EPIDEM for prediction of the occurrence of late blight of potatoes and more recently EPIMAY for prediction of southern corn leaf blight (28). Such simulation models are needed for crops where pest protection is necessary for production.

Methods of determining moisture content of standing crops using temperature and relative humidity of the air have recently been attempted (5). At present most economic models developed for grain harvesting equipment requirements assume a constant or a logarithmic decrease in grain moisture (14). An effective economic model for decision-making with respect to harvest equipment requires a fairly precise estimate of the daily moisture content of standing grain.

Engineering Data

The present form of data prepared by engineers is no longer adequate to realize the full potential of economic models. Machinery operating costs such as fuel, lubrication, etc. are relatively easy to determine. By comparison, other costs, particularly repair costs, are extremely difficult to evaluate.

Repair costs may be considered as being composed of two parts. The first is the actual cost of a repair, and the second is the cost of a delay in the cropping operation due to machine "down time" while repairs are made. It is difficult to obtain repair cost data because farmers rarely keep accurate records. The records that are kept often underestimate true repair costs because many repairs are made by one farmer and not by another who prefers to hire a mechanic or buy replacement parts, or both. Bowers and Hunt (2) have developed a mathematical model to describe the interrelations between equipment initial costs and expected repair costs based on the life and usage of the machine.

It is difficult to predict the frequency of breakdowns and machine down time using linear or nonlinear functions because breakdowns (varying in severity from minor to major overhauls) occur at uneven intervals during the life-span of the equipment. Estimates of the frequency of breakdowns can be derived from probability distributions that require introduction of the reliability of the machine (7, 11). The reliability and amount of repairs go hand and hand; both can be related to the initial cost,

quality of the machine, number of hours of annual use, age, and several indirect factors such as general operational attitudes of the farmer, use inspections, type of terrain, type of crop, and yield of the crop.

During the peak of a cropping operation the cost of delay due to a machine failure is potentially much greater than the cost of repair because of the losses due to untimely crop operations (see "Losses Due to Untimely Operations"). The crop loss may be magnified because modern farming employs a system of machines and a stoppage in any of the links may stop the entire system. For example, if a corn dryer fails during harvest the farmer may be forced to cease harvesting until the drying link is restored or seek a less profitable alternative.

The capacity of a machine must be known to calculate costs and returns. Techniques have been developed in the past to determine the average capacity of a machine, based on its physical dimensions and on efficiency coefficients to account for discrepancies between the theoretical capacity, and the actual capacity of the machine in the field (10, 16, 22). Probabilistic data on actual machine capacities are now required if the economic impact of the timeliness of crop operation (see "Losses Due to Untimely Operations") is to be investigated properly, as the actual capacity of a machine depends on its size, its reliability, power available, the condition of the crop, and the probability of having suitable operating conditions.

In addition, the capacity of some machines is very closely dependent on meteorological conditions (see "Agrometeorological Data"). For example, the capacity of a dryer depends on air humidity and crop moisture. There are models in the literature concerned with the simulation of the physical phenomena of actual drying (24) but they are not very suitable to determine a dryer's capacity for various meteorological and crop conditions for economic models.

Other data that would be very useful in an economic model are the field losses caused by a machine operation. The most important of these losses is caused by harvest machinery. A corn picker, for example, may lose an average of 10% of crop yield. This represents a significant part of potential crop return. It would be desirable to be able to associate machine losses with the condition of the crop at the time of the operation and the losses occurring from different machines, with different adjustments. These field losses of a machine should be related to the

type of machine, travelling speed, and condition of the crop (e.g., the moisture content, time in the harvest season, and the extent of lodging).

An economic model can consider trade-offs among machine field losses, drying costs and capacity, harvest capacity, and potential yields. At present, very little information is available to be able to establish relationships among these factors.

SUMMARY AND CONCLUSIONS

This paper had four objectives: to summarize an economic model of farm machinery investment; to examine the data required in the model; to determine which data are available and which are not; and to indicate research needed to derive and interpret the data.

Economic models for investment in farm machinery were suggested and the data required by them were outlined, partly with the aid of diagrams (Figures 1 and 2). Much of the data required (e.g., the financial alternatives and taxation implications) by the economic models were not discussed because they are of more direct interest to the agricultural economist.

Considerable emphasis has been given to data concerned with the costs of untimely field operations and on the variables that influence these costs. The work of several agricultural disciplines is needed to establish the variables and determine the costs. Recent advances in decision-making theories in economics, combined with advances in computing technology, have made it possible to quantify many more variables than was previously possible. Thus, more data can be assessed by the decision maker provided they are in a form that can be used in the new decision-making models. Recommendations for better and more relevant data collection in terms of frequencies and probability distributions have been given.

More specifically, the data required from three agricultural disciplines, viz agronomy, agrometeorology, and agricultural engineering, were examined. Although a great deal of data is available, much of it requires interpretation before it can be used in the economic model.

The research required to assemble and interpret information for an economic model of farm machinery investment calls for an integrated effort by many disciplines in agricultural science. This research is not easy as there are quite

significant communication difficulties even among researchers who have had similar undergraduate training in agriculture, and who have common interests in specific agricultural problems. The returns from interdisciplinary research may be quite high, however. For the researcher, interdisciplinary research can be intellectually stimulating. For the ultimate consumer of the research, the farmer, the research results are much more likely to be useful as a wider whole-farm approach is taken to farm management problems.

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