OPTIMIZATION OF POWER AND MACHINERY SELECTION FOR AGRICULTURE

by

PINNAMANENI VENKATA NARAYANA RAO

B. Sc., Andhra University, Waltair, India, 1951
D. M. I. T., Madras Institute of Technology, Madras, India, 1954

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G. H. Larson

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INTRODUCTION

Today every government in the world is trying to explore the natural resources of its land and industrialize its country in order to improve the living standards of its people. The industrialization of a country utilizes much of its human labor and reduces the muscle power available for farming the land and producing food for its people. This requires the use of machines for doing the farming operations. Figure 1 shows the number of persons supported by each farm worker in the U.S.A. since 1820 (1). It indicates that each farm worker supported 4.12 persons in 1820. He is feeding 35 persons in 1967 and the figure is still going up. These figures show that the people hitherto employed in farming are drawn to work in industries. This reduction in the number of people engaged in farming, at the same time producing the amount of food needed for the country's increasing population and also for exporting to the less developed countries could have been achieved only by the utilization of machine power. According to the 1961 census, (2) and (3), India's population was 439.234 million out of which 99.5 million people were cultivators. These are the latest official figures available. It should be noted, however, that each farmer in India is feeding only 4.4 persons.

Tractors and plows are used to break open the land and make it fit for sowing seed; seed drills and planters are used for this purpose. With machines, the work can be performed at a much faster rate. Thus by doing the work at the proper time, the crop which would be damaged due

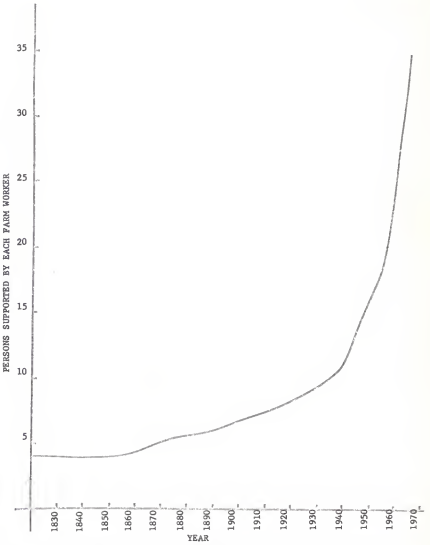

Fig. 1. Increase in production efficiency by farm workers in the U.S.A. from "What it Costs to Use Farm Machinery" by G. H. Larson, G. E. Fairbanks, and F. C. Fenton (1).

to adverse seasonal conditions could be saved.

The improved crop varieties, hybrid seeds, better soil and water conservation practices, insect, pest and weed control chemicals, chemical fertilizers, irrigation and other factors have had their part in increasing the agricultural production. However, the most important factor which increased the production per agricultural worker was the utilization of larger and more powerful machines--both for general and specific purposes.

Machines can be used to increase output per person, output per acre or both. In western countries, the machines are used mostly towards increasing output per person which is labor-saving. In Japan, however, machines are used towards raising yield per acre (4). This supports the following general observation--larger and powerful machines are used on farms in the U.S.A. which are designed primarily for labor-saving whereas smaller machines which are suitable to work in smaller holdings and are designed to give better performance of tillage, sowing, spraying, and harvesting help to obtain higher yields in Japan.

In India 60 per cent of the land holdings are less than 5 acres and 33 per cent are larger than 25 acres (5). The state of Andhra Pradesh occupies an important position and plays a significant role in the agricultural economy of India. The state cultivates 8.3 million acres every year and produces about 4.4 million tons of rice (6).

The small sized farms accompanied by the following other factors are impeding the agricultural mechanization.

Low per capita income.

High population density.

Surplus labor during the greater portion of the growing season.

Lack of services to support mechanisation.

Inadequate transport facilities.

However a few factors which have enabled and are assisting the agricultural mechanisation are (7)

1. development of industrial production,
2. development of machines for small farms,
3. labor shortage for transplanting and harvesting,
4. shortage of work animals which are too weak and slow,
5. government sympathetic to mechanisation attempts.

To encourage mechanization of agriculture, the government has purchased bulldozers, tractors, moldboard and disk plows, harrows, oil-engine pump-sets and has employed engineers to manage these machines. The engineers are responsible for the maintenance and repairs of these machines and to work them in the farmer's fields duly collecting the prescribed hire charges. Encouraged by the success of this scheme, the government later purchased tractors, implements, oil engine and electric-motor pump-sets and supplied them on hire purchase basis to the enthusiastic farmers.

As per the 1961 census report (2), the following agricultural machinery are owned by farmers in India.

Tractors for tillage and transport	31,000
Oil engine pump-sets for lift irrigation	230,000
Electric motor pump-sets for lift irrigation	160,000

To produce good quality seed, the Government has started seed farms in each district of the state. The seed farms are of 100 acres or more--a few are about 400 acres in size. In addition the government is also encouraging co-operative farming.

Purchase of machines for agricultural mechanization requires larger investments. The additional money spent on the machines must bring back the farmer rewards in terms of net profit from the land. This requires a judicious selection of machinery suitable for the particular farm.

OBJECTIVE

The primary purpose of this study is to investigate the least cost method of selection of power and implement's width for a 100-acre farm in the State of Andhra Pradesh, India. The number of operations and variety of equipment used on most farms makes machinery selection problems differ from those faced by other businesses of comparable size. In addition farm machinery use is seasonal. Total annual use may be only a few days each year. This presents a different type of selection problem as contrasted to the problem of selection of industrial machinery. Because of these and other factors, the efficient selection of farm machinery is a difficult problem. Almost each farm has to be studied independently to equip it with suitable size, number and type of machines with economic consideration.

REVIEW OF LITERATURE

Depreciation

There are several methods available to the farmer to evaluate the depreciation cost of his machines. These are discussed later under the heading "Procedure--Cost Factors." G. H. Larson (8) observed that the depreciation may represent as much as 40 to 45 per cent of the total machine cost or as much as 60 per cent of the ownership costs. He further remarked that the declining balance method of depreciation permits the farmer to write off nearly two-thirds the original cost during the first half of the normal equipment life. He developed an equation for calculating the value of a machine at the end of a year using the declining balance method of depreciation.

$$V = C\ (1 - \frac{R}{L})^X$$

where V = value at the end of a year in question.

C = original cost of the machine.

R = rate of depreciation claimed (for maximum rate, R = 2).

L = estimated service life.

X = year in question.

K. L. Pfundstein (9) observed that for items of minor value, the simple straight-line method of 10 per cent per year for a ten year period of usefulness may suffice. He also found that for tractors and other machinery of major importance, a declining-balance rate of 20 per cent applied to the tractor value at the beginning of each year correlates quite well with published trade-in values, particularly during the two-to-six year period.

Figure 2 (8) shows the relation between value and age of tractor with different methods of depreciation. It can be seen from the figure that the declining balance method will not permit total depreciation at the end of the useful life of the machine but does approach the 10 per cent salvage value often used with the straight line method. But if the declining balance method is followed with the straight line method when advantageous it would be possible to depreciate the full amount.

The depreciation rate depends on the service life of the machine. A survey conducted by George H. Sefarovich (10) revealed that, in 1962, the average age of tractors on farms was about 11 years and the average age of tractors discarded was about 15 years. He predicts that by 1970, the average age of tractors on farms would increase to almost 13 years and the average discard age would decrease to less than 14 years. With this many years of service life, the declining balance method approaches the more realistic "as is" value (8).

Repair Costs

Next to depreciation, repair costs are usually considered second in order of importance. After studying the yearly repair cost figures for a period of ten years on seven tractors, G. H. Larson (8) has evolved the following relationship between repair costs and the use of a machine.

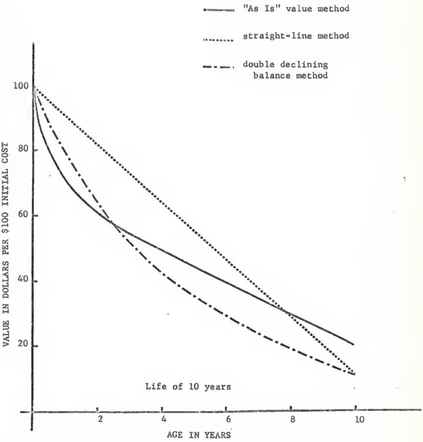

Fig. 2. Relationship between value and age of tractor with different methods of depreciation.
From "Evaluation of Factors Affecting Operating Costs of Farm Equipment" by G. H. Larson (8).

$$Y = 0.314\ X^{1.61}$$

where Y = repair cost in per cent of new cost.

X = age of tractor in years.

K. L. Pfundstein (9) charged the repair costs as a percentage of initial tractor cost per 1000 hours of use per year for a ten year period. These rates were 3 per cent for L. P. gas tractors, 3.5 per cent for gasoline tractors and 4 per cent for diesel tractors.

The study made by the University of Illinois and reported by Mark Zimmerman (11) revealed that the engine accounts for about half the repair costs of both gasoline and diesel tractors. It was found at the end of a 7-year's observation of six different tractors of about 50 hp, that the cumulative repair cost per hour of operation was 22.5 cents for diesel tractors and 19.8 cents for gasoline tractors. He further reported (12) that the repair costs came to about 50 per cent of the original price for both types of tractors at the end of 7 years' period. He showed that the repair costs closely follow a reverse sum-of-digits curve for the 10-year life of the tractor as shown in Fig. 3.

The study further revealed that the total repair costs go up with tractor's age and use but the cost per hour is less at higher use levels. By holding the other cost factors such as depreciation, interest, taxes, insurance and fuel, it was shown that the extent of repair costs largely determines the year of least cost operation. For the tractors under study, it had not been reached at the end of 10 years with low repair costs and with high repair costs it came at the fifth year.

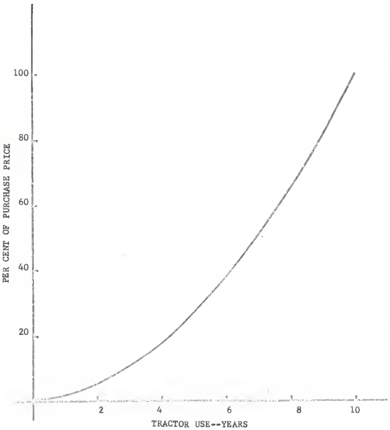

Fig. 3. Repair costs expressed as a per cent of original cost. From "Putting Tractor Repair Costs in Perspective With Respect to Purchase Price, Hours of Use Annually and Other Costs," by Mark Zimmerman (12).

Replacement of Existing Machines

The existing machine has to be replaced when it ceases to function physically or when it does not provide service as economically as a replacement. The factors that need consideration for replacement of a machine are

1. Excessive maintenance.
2. Inadequate capacity.
3. Obsolescence.
4. Decreased efficiency.
5. Ability of a new machine to combine a number of distinct operations formerly done by more than one machine.
6. High resale value of old machine.
7. Greater returns per dollar invested.
8. New machine more dependable and easier to operate.

Among the above mentioned factors, the excessive maintenance and the obsolescence of a machine have greatest influence in deciding when an existing machine is to be replaced. G. H. Larson (8) proposed a minimum-cost method for replacing a machine. To understand this method it is necessary to define two types of unit costs which are derived from the total cost of operation. Assuming that a farm machine is used a constant amount each year the unit of output can be taken as one year. Then the average total cost to-date is the total costs of operation divided by the number of years to-date. The marginal cost is the amount of operating costs added to the total costs up to previous year, during the year under consideration. The method suggested is when the marginal costs equal the average total cost to-date. When this occurs a point has been reached on the production function curve which is considered to be the maximum profit point, and when this point is reached the average total cost curve will be at a minimum. From a study of seven tractors, he found that the average cost to-date and marginal cost will be equal at about the end of the ninth year. He noted that the rate of depreciation and rate of repairs have the greatest influence on determining the year when the lowest operating costs will occur.

Selection of Type and Size of a Machine

While selecting a set of machinery for a farm, one has to consider several factors such as the effectiveness of the machine to provide proper soil-plant relationships, to perform the job in consideration to timeliness and minimum cost, the fuel to be used and others.

K. L. Pfundstein (9) has developed a relationship for comparing the economies of using gasoline, diesel and L. P. gas tractors. He gave the following expression for the total cost of owning and operating a tractor.

$$\$ \text{ cost} = \$ \, PZ + \$ \, UR + \$ \, L$$

where P = purchase price.

Z = cost factors related to purchase price.

U = hours of annual use.

R = cost factors related to amount of use.

L = independent cost factors such as liability and property damage insurance.

He further derived an expression for determining the number of hours of tractor use required for amoritizing the higher diesel costs by using the relation that the total costs of ownership and operation of a gasoline and of diesel tractors become equal at some period.

$$\$ \text{ cost (gasoline tractor)} = \$ \text{ cost (diesel tractor)}$$

$$P_G Z_G + UR_G + L_G = P_D Z_D + UR_D + L_D$$

From this we get,

$$U = \frac{(P_D Z_D - P_G Z_G) + (L_D - L_G)}{(R_G - R_D)}$$

The subscripts D and G refer to diesel and gasoline tractors.

To simplify the calculations, Pfundstein (9) combined the terms Z and L and arrived at a constant K as a factor of purchase price. Thus K represents fixed-cost items such as depreciation, taxes, insurance and interest. For calculating the denominator $(R_G - R_D)$, he gave the following expression.

$$(R_G - R_D) = S\ (0.0035\ P_G - 0.004\ P_D) - 1.2 + (0.75\ FC_G - 0.75\ FC_D)$$

where S is a constant relating service and maintenance costs to hours of use.

F is fuel consumption from Nebraska test 'E', gallons/hour.

C is fuel price, cents per gallon.

The coefficients 0.0035 and 0.004 relate to service and maintenance of gasoline and diesel tractors respectively. The coefficient 0.75 is used assuming that the field fuel consumption will be about three-fourths of the fuel consumption from Nebraska test 'E'. In this test, the tractor engine is tested for twenty minutes each at rated load, no load, one-half rated load, maximum load with wide open throttle valve, one-fourth rated load, and three-fourths rated load when the engine is controlled by the governor. The average result of this test is taken as the average horsepower and fuel consumption, since a tractor is subjected to varying loads in the field. He suggested that this figure can be altered depending on the actual field conditions. So the final equation for U becomes

$$U = \frac{K\ (P_D - P_G)}{S\ (0.0035\ P_G - 0.004\ P_D) - 1.2 + (0.75\ FC_G - 0.75\ FC_D)}$$

Here U is the hundred of hours of tractor use required per year for amortization of higher diesel costs or "break-even."

The following are the values of K and S furnished by him.

Amortization time years	K	S
1	0.2942	0.1818
2	0.2658	0.2727
3	0.2412	0.3636
4	0.2199	0.4545
5	0.2012	0.5454
6	0.1849	0.6364
7	0.1706	0.7273
8	0.1580	0.8182
9	0.1469	0.9091
10	0.1371	1.0000

Using this relationship, he constructed tables to give the number of hours of use per year required to amortize the higher costs of diesel. A sample table is furnished under Appendix A.

Donnel R. Hunt (13) made an extensive study and proposed a set of equations for selecting a least-cost width of implement and least cost of power, both based on timeliness factor. These equations are derived seperately under the heading "Procedure--Minimum Cost Method."

For implement least-cost width.

$$W^2 = \frac{8.25}{FC\ \%\ P} \sum \frac{A_i}{S_i E_i} (L_i + T_i + K_i Y_i V_i)$$

where W = least-cost width of implement.

FC % = fixed cost percentage, the decimal part of the implement purchase price.

P = purchase price of implement per foot width.

A = number of acres over which the implement is worked annually.

S = forward speed miles per hour.

E = field efficiency, per cent.

L = cost of labor per hour.

T = tractor fixed cost charge.

K = timeliness factor, 1/hour.

Y = potential total crop yield, tons etc.

V = value of crop per ton.

For tractor power.

$$hp^2 = \sum \frac{0.022\ A_i\ ff_i}{FC\ \%\ t\ E_i} (L_i + K_i Y_i V_i) + \sum \frac{L_i}{FC\ \%\ t} (1.1\ D_i W_i + G_i W_i)$$

where hp = horsepower.

ff_i = force factor lbs/ft width.

t = tractor purchase price per usable horsepower.

D = one-way distance from field to farmstead, miles.

W = amount of material transported annually, tons.

G = energy factor for stationary operations.

The subscript i and summation sign Σ are used to take into consideration all the operations performed by a single machine, implement or tractor.

These equations have been derived by computing the total cost of operation and differentiating it with respect to the variable which is w-width in the case of implements or hp-horsepower in the case of tractor.

David L. Horn (14) made use of the similar principle for determining the minimum cost pipe diameter for a border irrigation pipeline design.

PROCEDURE

Cost Factors

The factors that affect the cost of using farm machinery may be grouped under two headings.

I. Fixed or ownership costs, which include:

(a) Depreciation

(b) Interest on investment.

(c) Insurance.

(d) Taxes.

(e) Shelter.

II. Operating costs, which include:

(a) Repairs.

(b) Maintenance and lubrication.

(c) Fuel and oil consumption.

(d) Labor.

Fixed or Ownership Costs

The fixed or ownership costs are about the same regardless of the amount of annual use of the machine. Of course, depreciation depends somewhat on the amount of use which determines the life period of the machine. The latter in turn depends on the care and maintenance given to the machine.

Depreciation. Depreciation is defined as the loss in value and service capacity resulting from natural wear in use, obsolescence, accidental damage, rust, corrosion, and weathering. It is usually expressed as a percentage of the original cost of the machine.

The rate of depreciation depends on many factors such as:

(1) The original price of the machine--labor saving attachments such as power steering, hydraulic controls, and similar equipment, increase the original price of the machine and so the depreciation rate.

(2) The service life of the machine--this depends on the rate of wear which again depends on operating conditions, skill of the operator,

care and maintenance given to the machine and finally the quality or design of the machine itself; the service life has to be estimated from experience and the results of previous farm machinery surveys and is not possible to wait until the machine is worn out to calculate its life and determine depreciation rate.

(3) Obsolescence--its effect on depreciation rate is difficult to evaluate; new developments in the design of a machine either to increase its efficiency or decrease the labor involved in its operation or improve the quality of work turned out will make the existing machine obsolete even before its life period; it is said that tractor mounted implements are apt to have their obsolescence determined by the life of the tractor upon which they are mounted.

Methods of Estimating Depreciation. After estimating the expected service life of a machine, one of the following methods can be used to calculate annual depreciation rate.

1. Straight-line method.
2. Declining balance method.
3. Sum of the digits method.

Straight-line Depreciation Method: In this method, the value of a machine is reduced by an equal amount each year during its useful life. This is simplest and widely used method. A machine depreciates less by this method the first few years than its resale value would indicate. If the expected service life of a machine is 10 years, then 10 per cent of the original cost will be the depreciation value for each year. For many purposes this procedure is satisfactory, but since the machines usually have a considerable trade-in value it has to be accounted for. It is generally assumed that 10 per cent of the original cost will be the value of the machine at the end of its service life.

The following table indicates the amount of depreciation in per cent of initial cost for years indicated as determined by the straight-line method of depreciation, assuming 10 per cent trade-in value.

Table 1. Annual depreciation rate as a per cent of initial cost, as indicated by the straight-line depreciation method.

Service life, years	Annual depreciation, percentage of initial cost
5	18.00
6	15.00
7	12.86
8	11.25
9	10.00
10	9.00
11	8.18
12	7.50

Declining Balance Method: It is a constant percentage method. It permits a depreciation rate not to exceed twice the straight-line rate (1). This method depreciates about two-thirds of the original cost during the first half of the machine's service life. If the service life of a machine is 10 years, the maximum depreciation rate allowed by this declining balance method is 20 per cent of the original cost for the first year and the same percentage of the remaining value of the machine at the end of a year for each succeeding year. K. L. Pfundstein (9) observed that this rate correlates well with the published trade-in values, particularly during the first two- to six-year period. He further observed that the use of this declining balance method eliminates the need to establish an absolute useful life figure, since rates other than 20 per cent will have only negligible effects on remaining value during the latter years of tractor life.

Sum of the Digits Method: It also permits a higher rate of depreciation during the early life of a machine and encourages early trade-in. This method depreciates the value of a machine to zero at the end of its expected useful life. The following formula can be used to calculate the depreciation by this method.

$$D = \frac{2\ (L + 1 - Y)\ C}{L\ (L + 1)}$$

where D = depreciation for the year in question.

L = expected service life.

Y = year in question.

C = initial cost of the machine.

Thus for a service life of 10 years, the depreciation is $\frac{10}{55}$ C for the first year, $\frac{9}{55}$ C for the second year, so on and finally $\frac{1}{55}$ C for the tenth year. By this method the initial value is fully depreciated at the end of the expected useful life of a machine.

<u>Interest on Investment</u>. Since money invested to buy a machine cannot be used for any other income earning purposes, interest has to be

charged on it and included as one of the ownership costs. The amount invested in a machine decreases year to year since an amount is written-off each year as depreciation. It is convenient to charge the same rate of interest for each year of the machine's life. With the straight-line depreciation method, interest is charged over the average investment which is equal to one-half the sum of first cost and the trade-in value. With the other two methods of depreciation also, the average value of a machine for the year in question is determined and interest is charged accordingly. A wide range of interest rates, 4 to 10 per cent, is applied to farm machinery, depending upon the financial arrangements. Usually interest is charged at 6 per cent per annum (15). K. L. Pfundstein (9) observed that a 7 per cent rate was most typical during 1960.

Taxes. Farm machinery in the U.S.A. is taxed at the same rate as other farm property. Larson et al. (1) have estimated that about 1 per cent of the initial cost of a machine will go annually towards property tax including the sales tax already paid for the machine. K. L. Pfundstein (9) also estimated the same figure. American Society of Agricultural Engineers recommend a rate of 2 per cent (15).

In India, no separate tax is charged on farm property. The government collects land tax every year. This tax varies from one locality to the other depending on the fertility of the land. In the areas where government supplies irrigation water the rate of tax is higher.

Insurance. Cost of insuring farm machinery against loss by fire, wind storm, floods, and accident liability is justifiable because a farmer carries the risk if he does not insure. Larson et al. (1) suggested an annual charge of 0.25 per cent per year of initial cost to cover farm machinery insurance. According to K. L. Pfundstein (9), the fire and comprehensive coverage based on the original purchase price of tractors and L. P. gas storage, is at $10.45 per $1,000 valuation and the liability and property damage for the tractor only at $10.00 annually. He estimated that the above rates amount to slightly more than 1 per cent of the tractor price per year. American Society of Agricultural Engineers also recommend a rate of 1 per cent (15).

Shelter. Sheltered machines will usually give a longer service than unsheltered ones. Larson et al. (1) recommend an annual charge of 1 per cent of the initial price of a machine towards the cost of sheltering the machine. American Society of Agricultural Engineers also recommend a rate of 1 per cent (15).

Operating Costs

Operating costs vary with the amount of use of the machine and as outlined under group II include charges towards repairs, maintenance, lubrication, fuel and oil consumption and labor.

Repairs. Repair costs depend on the amount and nature of use and the maintenance and care given to the machine. It includes the cost of the spare parts replaced, the cost of reconditioning the worn-out parts, say by welding and machining, and the wages paid to the mechanic and any other labor. Repair costs will be negligible during the first 2000 hours (approximately) of the machine's life and will in general increase as it becomes old.

In order to estimate the cost of using farm machinery, the repair costs are usually expressed as a certain percentage of the initial cost of the machine. Table 2 gives the percentage values to use in calculating annual repair costs for various farm machines (1).

Fuel and Oil Consumption. The cost of fuel and oil is the major expense in the operation of farm machines with power units. As it is not difficult to estimate the average consumption of fuel and oil, it is somewhat accurate to convert this consumption into money value for estimating operating costs under this item. Of course, the fuel and oil consumption varies with the load at which the machine is operated and also on the condition of the machine.

Barger et al. (16) suggest average values as shown in Table 3 for fuel consumption of various size tractors.

A survey conducted at South Dakota State College resulted in a method for estimating tractor fuel and oil consumption costs, when no accurate figures are available.

Fuel oil cost per day = Belt HP x 0.8 x fuel oil price per gallon

This formula allows for cost of grease.

American Society of Agricultural Engineers (15) recommend the following formula for estimating the average fuel consumption.

Table 2. Suggested values to use calculating annual repair costs for various farm machines.

Machine	Annual repairs in per cent of first cost of machine
Baler, hay, with engine	3.0
Binder, grain	2.5
Binder, row	2.5
Blower, forage	2.5
Combine, engine-driven	3.0
Combine, self-propelled	3.0
Cultivator, duck foot	3.5
Cultivator, listed corn	3.5
Cultivator, shovel	3.5
Cutter, ensilage	3.0
Drill, grain	1.5
Field forage harvester	5.0
Grinder, feed, burr	3.0
Grinder, feed, hammer	2.0
Harrow, disk	3.0
Harrow, drag	1.0
Lister	5.0
Loader, hay	1.5
Mower	3.5
Picker, corn	3.0
Planter, corn	2.0
Plow, one-way	5.0
Plow, trail-behind	7.0
Plow, tractor-mounted	7.0
Separator, cream	2.0
Sprayer, field	5.0
Spreader, manure	1.5
Rake, side-delivery	2.0
Rake, sweep	4.0
Thresher, grain	3.0
Tractor	3.5
Trailer	1.5
Weeder, rod	2.0
Windrower, self-propelled	4.0

From "What It Costs to Use Farm Machinery," by G. H. Larson et al., p. 26.

Table 3. Average gallons per hour, gasoline consumption.

Tractor size	Gallons per hour
One-plow	1.00
Two-plow, light	1.50
Two-plow, heavy	1.75
Three-plow	2.25
Four-plow	3.00

Average gasoline consumption, gls per hour = 0.06 x Maximum P.T.O. hp

Fuel consumption for other fuel type tractors can be estimated by substituting in the above formula the rated engine horsepower for the maximum power take-off horsepower, or by comparing them with a tractor engine of similar displacement.

Maintenance and Lubrication. In addition to the engine oil used to lubricate the internal parts of the engine viz. crankshaft main and connecting rod bearings, camshaft bearings, timing gears, pistons and piston pins, whose cost is included under the previous sub-heading "Fuel and Oil Consumption," lubricants have to be applied to the transmission and final drive, steering gear cases, and greases to clutch bearings, waterpump bearings, dynamo and starter bearings, wheel bearings, track rollers bearings, and idler and sprocket bearings and so forth. The labor required to apply the lubricants is more expensive than the cost of the lubricants. The cost of oil and fuel filters also will be included under this heading. The cost of these items is proportional to the amount of fuel consumed. American Society of Agricultural Engineers (15) recommend 15 per cent of the cost of fuel, in the absence of actual records. The total annual cost of lubricants and filters including the labor for applying the lubricants, will be as much as 1 per cent of the initial cost of the machine for a complicated machine like combine, and about 0.4 per cent for most other field machines. For machines used less than 100 hours annually and for most expensive machines an annual charge of 0.2 per cent of the initial cost is more realistic.

<u>Labor</u>. The wages paid to operate the machine will be a considerable amount and should be included in estimating the total cost of using farm machines. The value to use will vary with the location in the country under consideration.

Minimum Cost Method

Donnel R. Hunt (13) has derived the following equations for selecting the economic size of an implement and a tractor for a farm. This is done by writing an equation for the total annual cost of using an implement or a tractor, differentiating it with respect to the pertinent variable, i.e., width of the implement or the hp of the tractor, as the case may be, and setting it equal to zero.

The equations can be derived as follows.

$$C = \frac{SWE}{8.25} \text{ acres/hour}$$

where C = effective field capacity, acres/hour.

S = forward speed, mph.

W = effective width of the implement, feet.

E = field efficiency, expressed as a decimal. (For values see Table 4.)

$$A_c = Fc\ \%\ pw + \sum \frac{8.25\ A_i}{S_i w E_i} \quad (L_i + ow + fw + T_i)$$

where Ac = annual cost for the implement's use, dollars/year.

Fc % = fixed cost percentage, the decimal part of the implement purchase price, which is assumed to include all annual charges for depreciation, interest, and other fixed costs. Repairs and lubricants are included as fixed costs. (For values see Table 5.)

p = purchase price of implement per foot width, dollars/foot.

A = number of acres on which implement is used annually, acres/year.

L = cost of labor, dollars per hour.

w = width of implement, feet.

o = cost of engine oil, dollars per hour per foot of implement width.

f = cost of fuel, dollars per hour per foot of implement width.

T = tractor fixed cost charge, dollars per hour.

The subscript i and the summation sign Σ are used to make the equation apply to cases where a single implement may be used for more than one operation, each having different acreages, speeds, efficiencies, and hourly costs. Differentiating with respect to w:

$$\frac{d\ A_c}{dw} = Fc\ \%\ p - \Sigma \frac{8.25\ A_i}{S_i\ w^2\ E_i}\ (L_i + T_i)$$

Setting this to zero, we obtain

$$w^2 = \frac{8.25}{Fc\ \%\ p}\ \Sigma \frac{A_i}{S_i\ E_i}\quad (L_i + T_i)$$

This equation has only limited value when used for heavy draft tillage implements such as plows, disk harrows, chisel plows and others, which are relatively inexpensive for the amount of power they require. Use of this equation results in very large size of implements as it was assumed that T, tractor fixed cost charge was not affected by size of implement. Actually, it is the cost of power T, more than the cost of implement p, that determines the optimum size for heavy tillage implements.

<u>For Tractor Power</u>

Fixed costs/year = Fc % t hp dollars/year.

Costs for operating an implement $= \dfrac{(A\ \frac{\text{acres}}{\text{year}})\ (43560\ \frac{\text{ft}^2}{\text{acre}})\ (ff\ \frac{\text{lbs}}{\text{ft}})\ (L\ \frac{\$}{\text{hr}})\ (\frac{1}{60}\ \frac{\text{hr}}{\text{mt}})}{(\text{hp})\ (33{,}000\ \frac{\text{ft.lbs/mt}}{\text{hp}})\ (E)}$

$$= \frac{0.022\ A \times ff \times L}{hp \times E} \text{ dollars/year.}$$

Costs for operating an implement $= \sum \dfrac{0.022\ A_i\ ff_i}{hp\ E_i}\ (L_i)$ dollars/year.

Costs for transport and stationary work $= \sum \dfrac{L_i}{hp}\ (1.1\ D_iW_i + G_iW_i)$ dollars/year.

1.1 = constant obtained by using typical transport equipment with 5 per cent rolling resistance and an 80 per cent time efficiency. Fuel and oil consumptions are assumed to be directly related to hp.

$$\therefore\ Ac = Fc\ \%\ t\ hp + \sum \frac{0.022\ A_i\ ff_i}{hp\ E_i}\ (L_i) + \sum \frac{L_i}{hp}\ (1.1\ D_iW_i + G_iW_i)$$

where hp = usable horsepower.

t = purchase price of tractor per usable hp (dollars/hp).

ff = force factor, lbs per foot. (For values see Table 6.)

D = one-way distance from field to farmstead (miles).

G = energy factor for doing stationary work, hp hrs per ton. (For values see Table 7.)

W = amount of material transported annually, tons/year.

Differentiating with respect to hp

$$\frac{d\,A_c}{d\,hp} = Fc\ \%\ t - \sum \frac{0.022\ A_i\ ff_i}{hp^2\ E_i}\,(L_i) - \sum \frac{L_i}{hp^2}(1.1\ D_iW_i + G_iW_i)$$

Setting this equal to zero, we obtain

$$hp^2 = \sum \frac{0.022\ A_i\ ff_i}{E_i\ FC\ \%\ t}\ L_i + \sum \frac{L_i}{Fc\ \%\ t}\ (1.1\ D_iW_i + G_iW_i)$$

When timeliness factor is included the equations can be modified as follows.

For the economic width of an implement

$$W^2 = \frac{8.25}{Fc\ \%\ p} \sum \frac{A_i}{S_i\ E_i}\ (L_i + T_i + K_iY_iV_i)$$

For the economic horsepower of a tractor

$$hp^2 = \sum \frac{0.022\ A_i\ ff_i}{E_i\ Fc\ \%\ t}\ (L_i + K_iY_iV_i) + \sum \frac{L_i}{Fc\ \%\ t}\ (1.1\ D_iW_i + G_iW_i)$$

where K = timeliness factor (1/hour). (For values see Table 8.)

V = value of crop, dollars per ton.

Y = potential total crop, tons.

Table 4. Typical field efficiencies.

Operation	Field effcy. %
<u>Tillage</u>	
Harrowing (spike tooth)	70-85
Most other tillage operations (plowing, disking, cultivating, etc.)	75-90
<u>Planting</u>	
Drilling or fertilizing row crops or grain	60-80
Check-row planting of corn	50-65
<u>Harvesting</u>	
Combine harvesting	65-80
Picking corn	55-70
Picking cotton (spindle type picker)	60-75
Mowing	75-80
Raking	75-90
Direct windrowing of hay or grain	
(self-propelled windrower)	
In field with irrigated levees	65-80
In field with no levees	75-85
Baling hay	
Bales discharged onto ground	65-80
With bale wagon trailed behind	55-70
Field chopping	50-75

From ASAE Data: ASAE D230.1 "Farm Machinery Costs and Use," Agricultural Engineers Year book, 1966 (15).

Table 5. Values for fixed cost percentage.

Service life, years	Value of Fc %
3	.36
4	.29
5	.24
6	.21
7	.19
8	.17
9	.16
10	.15
11	.14
12	.13

From "Farm Power and Machinery Management," Donnel R. Hunt, Iowa State University Press, p. 208.

Table 6. Typical farm implement force factors.

Field operations	Force factors, lbs per foot width
Moldboard plowing	850
Listing	230
Field cultivating	240
Disk harrowing--stalk ground	250
--tilled ground	280
Row-crop planting	110
Small-grain drilling	115
Spike-tooth harrowing	105
Spring-tooth harrowing	180
Packing with corrugated roller	340
Row-crop cultivating	150
Rotary hoeing	100
Mowing	130
Conditioning hay	140
Raking	80
Baling	400
Flail-type forage harvesting	400
Field chopping--green forage	800
-- hay or straw	200
--row crops	1250
Combining	375
Corn picking	650
Applying anhydrous ammonia	400 lbs per knife

From "Farm Power and Machinery Management," Donnel R. Hunt, Iowa State University Press, p. 214.

Table 7. Farm processing energy requirements.

Crop handling and processing operations	G. Factor, hp hrs/ton
Loading manure	.2
Shelling corn	1.2
Grinding--ear corn	5.5
--shelled corn	8.0
--oats	17.0
Blowing silage	1.5
Crop drying	2.8

From "Farm Power and Machinery Management," Donnel R. Hunt, Iowa State University Press, p. 214.

Table 8. Timeliness factors.

Operation	K value
Seeding	.0003
Tillage	.00005
Cultivation	.0002
Grain harvesting	.0003
Hay harvesting	.0005
Green forage harvesting	.0001

From "Farm Power and Machinery Management," Donnel R. Hunt, Iowa State University Press, p. 209.

Typical Cultural Practice in Andhra Pradesh, India

There is a lot of diversity in Indian agriculture. The major crops cultivated in the State of Andhra Pradesh are:

1. Rice.
2. Peanut.
3. Sugar cane
4. Cotton.
5. Corn.
6. Sorghum and others.

Rice is cultivated in nearly 25 per cent of the area under all cultivated crops. Peanut and cotton are grown in the rice fallows. There is also a practice to take 2 or even 3 crops of rice per year from the same area where sufficient irrigation water is available. There are many varieties of rice ranging in duration from 95 to 220 days from seed to seed. Generally the following cultural practice is followed.

Crops	Growing Season
Rice	June to December
Peanut and cotton	December-January to April-May
Fallow	May and June

Table 9 shows the various agricultural operations, the period and days available for doing them.

Table 9. Various agricultural operations, the period and days available for doing them.

Operation	Period	Days available
Rice crop		
1. Preparatory cultivation plowing and harrowing	May-June	about 40 days
2. Sowing nurseries	First and second week of May	about 10 days
3. Watering the land, puddling and transplanting	Second and third week of June	about 15 days
4. Cultivation	Twice or Thrice depending on need	
5. Harvesting	November-December	about 15 days
6. Thrashing	December	about 20 days
Peanut crop		
1. Harrowing	December-January	about 10 days
2. Planting seed	December-January	about 10 days
3. Cultivation	Once or twice depending on need	
4. Harvesting	April-May	about 15 days

Implements Used in Rice Culture and Their Effectiveness on the Yield

S. N. Pradhan (17) summarized the various implements used and their effectiveness on the yield of rice.

1. Preparatory cultivation. The use of disk harrow and cultivator in combination with moldboard plow has been found to be nearly 2 to 2 1/2 times more labor saving and economical as compared to the conventional method of using wooden plow, without affecting the yield of the crop. In fact, the yield was the highest in the plot where disk harrow was used in combination with the moldboard plow.

2. Power tiller. There was no marked difference between using the power tiller once and twice in the initial preparation of land before direct sowing. One operation with the power tiller was found to be nearly 50 per cent more economical and about 14 times more labor saving than the use of the wooden plow in the initial preparation of land.

Puddling. It consists of thoroughly stirring and breaking up of the soil lumps to ensure easy planting and effective burying of weeds and green matter and is an important operation before transplanting of rice crop. It is usually done by the use of a wet land puddler.

Harvesting. Harvesting of rice crop is mostly done manually with the use of sickle. One person can harvest an area of 15 to 20 hundredths of an acre in a day of 8 hours. Because of this low turnout, the harvest is usually delayed resulting in a considerable crop loss. Complete mechanization of harvesting of rice by rice combines is not possible due to small holdings, unfavorable field and crop conditions, and other socio-economic factors. But there is adequate scope for mechanisation by using bullock power and using animal drawn reaper.

Thrashing. Threshing of paddy is generally done by manual labor by beating the stalks on a hard surface and then treading with bullocks. In recent times, the rice threshing is being done entirely by treading with a tractor. Japanese rice threshers are also being popularized.

Timeliness of Operations

Timeliness of machine operations is ordinarily considered as part of the more inclusive problem of machinery economics. Richey, Jacobson and Hall (18) in their discussion of selection of optimum capacity equipment, point out that the time available for field operations influences which machines should be selected for maximum profit, and the available time is, in turn, influenced by weather conditions. D. A. Link and C. W. Bockhop (19) have presented an analytical method for predicting the timeliness of operations of a system of field machinery under variable weather conditions. They described a mathematical model based on probability theory. They defined a number of terms, some of which are given below.

Holding interval: the interval of time between the arrival of a job and its completion.

Vacant interval: the interval of time between the completion of one job and the arrival of its successor.

They also described weather data in the form of probabilities and these are:

(1) For each time increment t_i, the probability that job A_1 will arrive during t_i. These probabilities are termed the arrival probabilities of A_1 and are denoted by $f_i(A_1)$.

(2) For each pair of time increments, t_i and t_j, and each job, A_r, the probability that, if A_r arrives during t_i, it will be completed during t_j. These are termed holding probabilities and are denoted by $h_{ij}(A_r)$.

(3) For each pair of time increments, t_i and t_j, and each pair of consecutive jobs, A_{r-1} and A_r, the probability that, if A_{r-1} is completed during t_i, A_r will arrive during t_j. These probabilities are termed vacant-interval probabilities and are denoted by $\phi_{ij}(A_r)$.

The basic equations of the model are for a single sequence, with no possibility of interference. Calculations with the equations begin with the first job in the sequence and proceed in sequential order to the left. The general equations for these calculations are:

$$(1) \qquad f_k(A_r) = \sum_{j=1}^{k} g_j(A_{r-1})\, \phi_{jk}(A_r), \qquad r \geq 1$$

and

$$(2) \qquad g_j(A_r) = \sum_{i=1}^{j} f_i(A_r)\, h_{ij}(A_r)$$

where $g_j(A_r)$ is the probability of completion of A_r during increment t_j. By forming the sums, the cumulative probabilities of arrival and completion are obtained. These are

$$(3) \qquad F_k(A_r) = \sum_{n=1}^{k} f_n(A_r)$$

and

$$(4) \qquad G_j(A_r) = \sum_{n=1}^{j} g_n(A_r)$$

These cumulative probabilities can be plotted as shown in Fig. 4. The vertical distance between the two curves is the probability that the job has arrived and has not been completed and is labeled $pr(Z_r)$. For the entire sequence A, the sum is

$$(5) \qquad pr(Z) = \sum_{r=1}^{N} pr(Z_r)$$ is the probability that some job in the sequence has arrived and has not been completed.

For a true measure of the probability that a farmer would be occupied with sequence A, it is necessary to take weather conditions into account. Thus, if w_{jr} is the probability of weather conditions favorable for A_r at some specified time during increment t_j,

$$(6) \qquad R_u(A) = \sum_{r=1}^{N} R_j(A_r) = \sum_{r=1}^{N} w_{jr}\, pr(Z_r)$$

where $R_j(A)$ is the probability that he will be occupied with some job in sequence A, and each product, $R_j(A_r)$, in the sum is the probability that he will be occupied with job A_r.

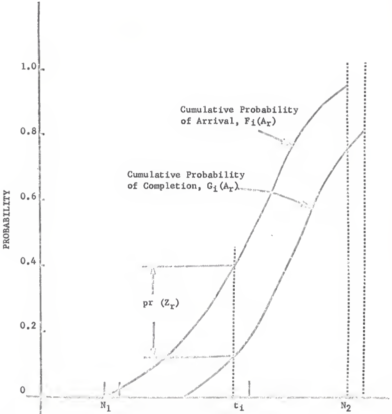

Fig. 4. Cumulative probabilities of arrival and completion. From "Influence of Weather on Timeliness of Operations of Systems of Farm Machines," by D. A. Link and C. W. Bockhop (19).

Holding Probability Calculations

These probabilities are dependent upon a number of parameters of the machinery system as well as on weather conditions. Suppose each time increment consists of M days and the job, A_r, being considered requires m_o good working days for completion. Suppose further that the probabilities of 0, 1, . . . M days in each increment being suitable for work on A_r have been obtained from weather records. Then, if A_r is started at the beginning of t_i and m_o is less than or equal to M

$$(7) \qquad h_{ii}(A_r) = \sum_{m=m_o}^{M} p_i(m) ,$$

where $p_i(m)$ is the probability of m good days during t_i, gives the first non zero entry in row i of the holding probability table for A_r. If m_o is greater than M, A_r cannot possibly be finished before the end of t_i and $h_{ii}(A_r)$ is zero. Now consider the sums

$$(8) \qquad p_{i,\ i+1}(m) = \sum_{k+L=m} p_i(k)p_{i+1}(L), \qquad 0 \leq m \leq 2M$$

Each product in these sums is the probability of k good days during t_i and L good days during t_{i+1}, for a total of k+L=m good days during the two increments. Thus

$$(9) \qquad h_{i,i+1}(A_r) = \sum_{m=m_o}^{2M} p_{i,i+1}(m) - h_{ii}(A_r)$$

It is possible to proceed now to a new set of sums $p_{i,i+2}(m)$ and thence to $h_{i,i+2}(A_r)$, and so on, ultimately obtaining the entire i^{th} row of the holding probability table for A_r. The general equations for this process are

$$(10) \quad p_{ij}(m) = \sum_{K+L=m} p_{i,j-1}(K)\, p_j(L)\,, \qquad j \geq i+1$$

and

$$(11) \quad h_{ij}(A_r) = \sum_{m=m_o}^{(j-i+1)M} p_{ij}(m) - \sum_{k=1}^{j-1} h_{ik}(A_r)$$

Selection of Machinery

Crop	Annual acres	Yield per acre	Price per ton
Rice	100	one ton	Rs. 500
Peanut	100	0.5 ton	Rs. 1000

Machine Operations

Crop	Operation	Total acres
Rice	plowing once	100
	wet land puddling once	100
Peanut	harrowing once	100
	planting once	100
	cultivation once	100
	digging once	100

Calculation of Least-cost Width of Implement

The least-cost width equation is

$$w^2 = \frac{8.25}{Fc\ \%\ p} \sum \frac{A_i}{S_i\ E_i} \quad (L_i + T_i + K_i Y_i V_i)$$

Values assumed

Variable	Plow	Puddler	Harrow	Seed drill	Culti-vator	Cultivator for peanut digging
Fc %	15%	15%	15%	19%	15%	
p	Rs 300	400	250	500	150	
L	Rs 0.50	0.50	0.50	0.50	0.50	
T	Rs 4.00	4.00	4.00	4.00	4.00	
K	0.00005	0.0003	0.00005	0.0003	0.0002	
S	4	4	4	3	3	3
E	0.80	0.80	0.80	0.75	0.80	0.75
ff	850	500	250	110	150	250

Width of Plow

$$w^2 = \frac{8.25}{0.15 \times 300} \times \frac{100}{4 \times 0.80} \ (0.50 + 4.00 + 0.00005 \times 100 \times 500)$$

$$= 40 \text{ sq. ft.}$$

$$w = 6.32 \text{ ft.}$$

<u>Width of Wet Land Puddler</u>

$$w^2 = \frac{8.25}{0.15 \times 400} \times \frac{100}{4 \times 0.80} (0.50 + 4.00 + 0.0003 \times 100 \times 500)$$

$$= 83.9 \text{ sq. ft.}$$

$$w = 9.16 \text{ ft.}$$

<u>Width of Harrow</u>

$$w^2 = \frac{8.25}{0.15 \times 250} \quad \frac{100}{4 \times 0.80} (0.50 + 4.00 + 0.00005 \times 50 \times 1000)$$

$$= 48 \text{ sq. ft.}$$

$$w = 6.94 \text{ ft.}$$

<u>Width of Seed Drill</u>

$$w^2 = \frac{8.25}{0.19 \times 500} \times \frac{100}{3 \times 0.75} (0.50 + 4.00 + 0.0003 \times 50 \times 1000)$$

$$= 75 \text{ sq. ft.}$$

$$w = 8.68 \text{ ft.}$$

<u>Width of Cultivator</u>--used for cultivation and peanut digging

$$w^2 = \frac{8.25}{0.15 \times 150} \quad \frac{100 \times 2}{3 \times 0.8} (0.50 + 4.00 + 0.0002 \times 50 \times 1000)$$

$$= 444 \text{ sq. ft.}$$

$$w = 21 \text{ ft.}$$

Calculations for Least-cost Power

The equation for least-cost power is

$$hp^2 = \frac{0.022\ A_i ff_i}{E_i\ Fc\ \%\ t}\ (L_i + K_i Y_i V_i) + \frac{L_i}{Fc\ \%\ t}\ (1.1\ D_i W_i + G_i W_i)$$

Operation	Value of $\frac{A \times ff}{E}$ (L + KYV)		
Rice			
1. Plowing	$\frac{100 \times 850}{0.80}$ (0.50 + 0.00005 x 100 x 500)	=	318,500
2. Puddling	$\frac{100 \times 500}{0.80}$ (0.50 + 0.0003 x 100 x 500)	=	970,000
Peanut			
1. Harrowing	$\frac{100 \times 250}{0.80}$ (0.50 + 0.00005 x 50 x 1000)	=	94,000
2. Planting	$\frac{100 \times 110}{0.75}$ (0.50 + 0.0003 x 50 x 1000)	=	228,000
3. Cultivation	$\frac{100 \times 150}{0.80}$ (0.50 + 0.0002 x 50 x 1000)	=	197,000
4. Digging	$\frac{100 \times 250}{0.75}$ (0.50 + 0.0003 x 50 x 1000)	=	517,000
	Total		2324,500

Fc % for tractor 0.15

t, cost per usable hp . . Rs 600

$\therefore$ Field work $hp^2 \quad \frac{0.022}{0.15 \times 600} \times 2{,}324{,}500 = 570$

Transport Energy Requirements

Operation	D	W	DW	$\frac{1.1\ DWL}{Fc\ \%\ t}$
Transport of rice	2 miles	100	200	
Transport of peanut	2 miles	50	100	$\frac{1.1 \times 304 \times 0.50}{0.15 \times 600}$
Transport of manure, fertilizer, and pesticides	2 miles	2	4	= 1.86

Total $hp^2 = 570 + 1.86 = 571.86$.

Usable hp = 23.9

Assuming a transmission efficiency of about 70%

BHp = 34.2

So a tractor of about 35 BHP can be selected.

Selection of Implements Based on the Least-Cost Power

Variable	Plowing	Puddling	Harrowing	Planting	Cultivation
D. Depth of tillage, inches	8	6	4	4	4
P. Draft, lbs per sq. in.	10	8	8	8	8
S. Speed, mph	4	4	4	3	3

Width of Plow

$$w = \frac{375 \times hp}{DPS} = \frac{375 \times 25}{8 \times 10 \times 4} = 29 \text{ inches}$$

So a 2 x 14" mold board plow can be selected.

Width of Puddler

$$w = \frac{375 \times 25}{6 \times 8 \times 4} = 48.8 \text{ in.}$$

So a 4 foot puddler can be selected.

Width of Harrow

$$w = \frac{375 \times 25}{4 \times 8 \times 4} = 73 \text{ in.}$$

So a 6 foot disk harrow can be selected.

Width of Seed Drill

$$w = \frac{375 \times 25}{4 \times 8 \times 3} = 98 \text{ in.}$$

So a seed drill of 8 foot width can be selected.

Width of Cultivator

$$w = \frac{375 \times 25}{4 \times 8 \times 3} = 98 \text{ in.}$$

So a cultivator of 8 foot width can be selected.

Days Required for Completing the Operations

Field capacity $C = \frac{SWE}{8.25}$ acres/hour

$\therefore$ Area covered in a day of 10 hours $= \frac{10 \; SWE}{8.25}$ acres/day.

So days required to cover 100 acres = $\frac{100 \times 8.25}{10 \text{ SWE}} = \frac{82.5}{\text{SWE}}$ days.

Plowing

Days required to complete 100 acres = $\frac{82.5 \times 12}{4 \times 28 \times 0.8}$ = 11 days.

Puddling

Days required to complete 100 acres = $\frac{82.5}{4 \times 4 \times 0.8}$ = 6.5 days.

Harrowing

Days required to complete 100 acres = $\frac{82.5}{4 \times 6 \times 0.8}$ = 4.5 days.

Planting

Days required to complete 100 acres = $\frac{82.5}{3 \times 8 \times 0.75}$ = 4.5 days.

Cultivation

Days required to complete 100 acres = $\frac{82.5}{3 \times 8 \times 0.80}$ = 4.5 days.

Probability of Completion of Plowing

There is available about six weeks during May and June for plowing the fields. The probability of completing the plowing during this period can be calculated with the use of probability theory. James C. Frisby and C. W. Bockhop (19) have calculated the probability of completion of various cultural operations by making use of the mathematical model developed by David A. Link and C. W. Bockhop (19). For calculating the completion probability, the probability of any given day during a climatic week being good must be known. Monsoon season usually starts about the middle of June every year. Hence in the absence of any data, it can be assumed that the probability of any given day during a climatic week is 0.8. This is also in agreement with the values furnished by J. C. Frisby (20)--the probability of any day being good varies from 0.76 to 0.85 during May and June in the vicinity of Ames, Iowa, U.S.A.

The binomial distribution is of the form $(p+q)^n$, where p is the binomial probability that any given day will be good and q or (1-p), is the probability that any given day will be bad. Each term in the expansion gives, respectively, the probability that n, (n-1), . . . , 1, 0 good days will occur during the specified time increment. Assuming that a farmer will work for six days in a week, the binomial distribution becomes $(p+q)^6$ with p = 0.8 (assumed) and so q = 0.2. Expanding

$$(p+q)^6 = p^6 + 6\ p^5\ q + 15\ p^4\ q^2 + 20\ p^3\ q^3 + 15\ p^2\ q^4 + 6\ p\ q^5 + q^6.$$

In the expansion,

the term p^6 gives the probability that 6 days in a week are good,

the term $6\ p^5$ gives the probability that 5 days in a week are good

. . . . .

. . . . .

$6\ pq^5$ gives the probability that 1 day in a week is good

and

q^6 gives the probability that zero days in a week are good. These probabilities can be displayed as a column vector R.

$$
R = \begin{array}{l}
R_0 = q^6 = (0.2)^6 = 0.000064 \\
R_1 = 6\ pq^5 = 6(0.8)(0.2)^5 = 0.001536 \\
R_2 = 15\ p^2q^4 = 15(0.8)^2(0.2)^4 = 0.015360 \\
R_3 = 20\ p^3q^3 = 20(0.8)^3(0.2)^3 = 0.081920 \\
R_4 = 15\ p^4q^2 = 15(0.8)^4(0.2)^2 = 0.245760 \\
R_5 = 6\ p^5q = 6(0.8)^5(0.2) = 0.393216 \\
R_6 = p^6 = (0.8)^6 = 0.262144
\end{array}
$$

It has been shown already that 11 days are required to complete the plowing. So the probability of completing plowing during first week is nil. Now assuming the probability of any day being good during second week is also 0.8, the probability of 0 to 6 good days in the week can be similarly calculated. These probabilities are formed as a row vector S

S_0	S_1	S_2	S_3	S_4	S_5	S_6
0.000064	0.001536	0.015360	0.081920	0.245760	0.393216	0.262144

Then R x S matrix is formed.

	S_0	S_1	S_2	S_3	S_4	S_5	S_6
R_0	41×10^{-10}	9.8×10^{-8}	9.80×10^{-7}	5.25×10^{-6}	1.57×10^{-5}	2.52×10^{-5}	1.68×10^{-5}
R_1	9.8×10^{-8}	2.36×10^{-6}	2.36×10^{-5}	1.25×10^{-4}	3.76×10^{-4}	6×10^{-4}	4×10^{-4}
R_2	9.8×10^{-7}	2.36×10^{-5}	2.36×10^{-4}	1.25×10^{-3}	3.76×10^{-3}	6×10^{-3}	4×10^{-3}
R_3	5.25×10^{-6}	1.26×10^{-4}	1.26×10^{-3}	6.70×10^{-3}	2×10^{-2}	3.2×10^{-2}	2.1×10^{-2}
R_4	1.57×10^{-5}	3.80×10^{-4}	3.80×10^{-3}	2×10^{-2}	6.05×10^{-2}	9.7×10^{-2}	6.45×10^{-2}
R_5	2.52×10^{-5}	6.05×10^{-4}	6.05×10^{-3}	3.22×10^{-2}	9.65×10^{-2}	1.55×10^{-1}	0.104
R_6	1.68×10^{-5}	4×10^{-4}	4×10^{-3}	2.15×10^{-2}	6.45×10^{-2}	0.103	6.9×10^{-2}

To find the probability of at least 11 good days during the first and second weeks, sum all the elements of the above matrix for which the subscripts total 11 or more. Thus probability of getting at least 11 good days during the first and second weeks is 0.276 as shown below.

$$R_5S_6 = 0.104$$
$$R_6S_5 = 0.103$$
$$R_6S_6 = \underline{0.069}$$
$$0.276$$

As this probability is very low, a new column vector V is formed from the above R x S matrix to get the probability of 0 to 10 good days during the first and second weeks combined, as shown below.

$$V_0 = R_0S_0 = 41 \times 10^{-10}$$

$$V_1 = R_1S_0 + R_0S_1 = 19.6 \times 10^{-8}$$

$$V_2 = R_2S_0 + R_1S_1 + R_0S_2 = 43.2 \times 10^{-7}$$

$$V_3 = R_3S_0 + R_2S_1 + R_1S_2 + R_0S_3 = 57.7 \times 10^{-6}$$

$$V_4 = R_4S_0 + R_3S_1 + R_2S_2 + R_1S_3 + R_0S_4 = 51.94 \times 10^{-5}$$

$$V_5 = R_5S_0 + \ldots + R_0S_5 = 331.64 \times 10^{-5}$$

$$V_6 = R_6S_0 + \ldots + R_0S_6 = 1.55 \times 10^{-2}$$

$$V_7 = R_7S_0 + \ldots + R_0S_7 = 5.29 \times 10^{-2}$$

$$V_8 = R_8S_0 + \ldots + R_0S_8 = 1.32 \times 10^{-1}$$

$$V_9 = R_9S_0 + \ldots + R_0S_9 = 2.36 \times 10^{-1}$$

$$V_{10} = R_{10}S_0 + \ldots + R_0S_{10} = 2.84 \times 10^{-1}$$

Again assuming that any day in the third week being good as 0.8, the probability of 0 to 6 good days are calculatsd and another column vector T is formed. From this the following V x T matrix is written.

	T_0	T_1	T_2	T_3	T_4	T_5	T_6
V_0							
V_1							
V_2							
V_3							
V_4							
V_5							8.7×10^{-4}
V_6						6.2×10^{-3}	4.05×10^{-3}
V_7					1.3×10^{-2}	2.12×10^{-2}	1.39×10^{-2}
V_8				1.8×10^{-2}	3.24×10^{-2}	5.27×10^{-2}	3.46×10^{-2}
V_9			3.64×10^{-3}	1.93×10^{-2}	5.8×10^{-2}	9.45×10^{-2}	6.2×10^{-2}
V_{10}		4.37×10^{-4}	4.37×10^{-3}	2.33×10^{-2}	7×10^{-2}	1.13×10^{-1}	7.45×10^{-2}

From this matrix the probability of getting at least 11 good days during third week is calculated as below.

$$V_5T_6 + V_6T_5 + V_6T_6 + V_7T_4 + V_7T_5 + V_7T_6 + V_8T_3 + V_8T_4 +$$

$$V_8T_5 + \ldots + V_{10}T_6 = 0.72$$

So the total probability of getting 11 good days during the first, second and third weeks is 0.276 + 0.72 = 0.996 or 99.6 per cent. This shows that the plowing of 100 acres can be completed in about 3 weeks time.

RECOMMENDATIONS FOR ADDITIONAL WORK

In farm management, timeliness of agricultural operations is an important aspect. The values of timeliness factors for various agricultural operations, worked out by Donnel R. Hunt will not be useful for Indian conditions because of differences in climate and cultural operations. It will be an interesting work to develop the values of timeliness factors for various agricultural operations in India. To develop these values, it may be necessary to know the probability of completing various agricultural operations in time. Again a knowledge of the probability of any day of a climatic week being good is required to calculate the probability of completing an agricultural operation in time. Thus development of values for the probability of any day of a climatic week being good for agricultural operations is another interesting field of study.

SUMMARY

The cost of operation of farm machinery is divided into fixed costs and operating costs. Fixed costs remain about the same regardless of the amount of annual use of the machine. Operating costs vary with the amount of annual use of the machine. The minimum cost method defined by Donnel R. Hunt is used to select a set of machinery for a 100 acre farm in Andhra Pradesh, India. The major crops cultivated in the state are rice, peanut, sugar cane, cotton, corn, sorghum and others. In this study, the following cultural practice usually followed in the state is chosen.

Rice -- Peanut - Fallow.

The method defined by Donnel R. Hunt gave larger values of width for heavy draft tillage implements like plows, and puddlers since these implements are relatively inexpensive when compared with the amount of power they use. To match the least-cost width of these implements a huge tractor has to be selected. But when the method is used to select a least-cost power, it gave a comparatively small tractor. Hence selection of a huge tractor to operate the heavy draft tillage implements will be uneconomical. As these implements are used only for a few days in a year and the tractor is the most used equipment on a farm it will be wiser and more economical to select the tractor of least-cost power and then select the implement's width based on the tractor's power.

Using the minimum-cost method, it is found that a tractor of 35 BHP is needed for the typical farm under consideration. Among the agricultural operations, plowing consumes maximum power. It is found that the 35 BHP tractor is quite sufficient to operate a 2 x 14" mold board plow. With this plow about 11 days are required to complete plowing of 100 acres. Usually about six weeks are available for the preparatory cultivation. It is found that the plowing of 100 acres can be completed in three weeks with a probability of 99.6 per cent.

The machinery recommended for the farm under study are listed below.

1. A 35 BHP Diesel tractor.
2. A 2 x 14" mold board plow.
3. A 4-foot wide wet-land puddler.
4. A 6-foot wide disk harrow.
5. An 8-foot wide seed-drill.
6. An 8-foot wide cultivator.

The computations involved in the machinery selection problems are lengthy and tedious. It will be easier to write mathematical models for the solutions of the problem and compute the numerical values by using digital computer. Mathematical models are written to the following three problems and they are solved using IBM 1620 computer.

1. Relationship between the size of machine and acres it will handle.

2. Determination of the year of service when a machine should be replaced.

3. Determination of the cost of operation per hour of a machine.

The mathematical models for the three problems, their computer programs and the output punched by the computer are given under Appendix B.

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APPENDICES

APPENDIX A

Annual Hours of Operation Required to Amortize Higher Costs of Diesel Tractors

Diesel Tractor price:	$3975				$4125			
Gasoline Tractor price:	3375				3325			
Difference in price	$ 600				$ 900			
	Gas	Die	Gas	Die	Gas	Die	Gas	Die
Fuel price, ¢ per gal	17.5	15.5	18.5	14.5	17.5	15.5	18.5	14.5
Fuel price Difference	2		4		2		4	
Amortization Time Years	Number of hours of use per year							
2	1410		1060		2170		1620	
4	1250		920		1960		1430	
6	1130		820		1820		1290	
8	1040		740		1740		1190	
10	980		680		1700		1120	

<u>How to use this table</u>

To use this table, the following information has to be obtained first.

1. The prices of gasoline and diesel tractors under consideration.
2. The prices of gasoline and diesel fuel.
3. The number of hours of tractor use per year.

For example consider the following.

Price of diesel tractor	$4125
Price of gasoline tractor	3325
Difference in price	900
Price of gasoline fuel	18.5 cents
Price of diesel fuel	14.5 cents
Fuel price difference	4 cents
Tractor use per year	1200 hours

With this information, refer the table under the column headed by $900 and 4 cents. In this column 1200 hours fall between 1290 and 1190. By moving across to the left-hand column, it is found that about seven years are required to amortize the higher diesel costs. This is the "break-even" point. Thus if the tractor is to be traded in seven years or less, the total cost of ownership and operation will be less for the gasoline tractor. On the other hand, the diesel tractor will show savings each year after seven years.

APPENDIX B

Relationship between the size of machine and acres it will handle.

$$hp = \frac{WDPS \times 88}{33000} = \frac{WDPS}{375}$$

$$\therefore \quad w = \frac{375 \times hp}{DPS} \text{ inches}$$

$$C = 5280 \times S \times \frac{W}{12} \times \frac{E}{100} \times \frac{10}{43560}$$

$$= \frac{SWE}{990} \text{ acres}$$

$$C = \frac{S}{990} \times \frac{375 \times hp}{DPS} \times E = \frac{0.38 \times hp \times E}{D \times P} \text{ acres per day of 10 hours}$$

If there are T good working days available for plowing

$$\text{Total number of acres plowed} = \frac{0.38 \times hp \times E \times T}{D \times P} \text{ acres}$$

where

- hp = useful drawbar horsepower of tractor.
- w = rated width of machine action, inches.
- D = depth of operation, inches.
- P = draft, lbs per sq. in.
- S = speed of operation, miles per hour.
- C = effective field capacity in acres per day of 10 hours.
- E = field efficiency in per cent.

Mathematical model for determining when a machine should be replaced.

The criteria for determining the replacement of a machine is when the marginal cost exceeds the average cost.

$$MC_y = D + R + \frac{V_{(y-1)}}{100}(I + J + 1.375)$$

$$AC_y = \frac{\sum_{j=1}^{y} MC_y}{y}$$

where

D = depreciation per year using sum of digits method.

$\therefore D = \frac{2(L+1-y)C}{L(L+1)}$

L = expected service life of the machine.

y = year in question.

C = initial cost of the machine.

R = repair costs per year.

$R = 0.314 \times y^{1.61} \times \frac{C}{100}$

V_y = value of the machine at the end of a year, y.

$V_y = V_{(y-1)} - D$

I = interest rate per year on the value of the machine at the beginning of a year, per cent.

J = insurance rate per year on the value of the machine at the beginning of a year, per cent.

Tax is charged at 2.75 per cent on 50 per cent of the value of the machine at the beginning of a year.

MC_y = marginal cost of operation for the year, y.

AC_y = average cost of operation at the end of a year, y.

Mathematical model for the cost of operation per hour of a machine.

Annual cost of operation = Marginal cost + cost of fuel, oil and operator.

It was already shown that

$$MC_y = D + R + \frac{V_{(y-1)}}{100} (I + J + 1.375)$$

Cost of fuel and oil can be estimated by using the formula.

Cost of fuel and oil per hour = 0.1 x BHP x Fuel oil price per gallon.

$$\therefore \text{ Cost of operation per hour} = \frac{MC_y}{X} + FC + W$$

where

X = number of hours of annual use of the machine.

FC = cost of fuel oil per hour.

W = wages paid to the operator per hour.

Symbols used in the computer program

C = Initial cost of the machine.

A = Interest rate per year, per cent.

B = Insurance rate per year, per cent.

V = Value of the machine at the end of a year.

D = Depreciation per year.

R = Repairs per year.

CM = Marginal cost per year.

TC = Total cost of operation up to the end of a year.

AC = Average cost at the end of a year.

SL = Expected service life of the machine.

X = Number of hours of annual use of the machine.

BHP = Usable belt horsepower of the machine.

FC = Cost of fuel oil per hour.

W = Wages paid to the operator per hour.

OC = Cost of fuel, oil and operator per hour.

CH = Cost of operation per hour.

HP = Usable drawbar horsepower of the machine.

G = Field efficiency, per cent.

T = Number of good days available during the season.

H = Depth of operation, inches.

P = Draft, lbs per sq. in.

```
C    MACH SIZE,ACRES
     READ 7,HP,G,T,H,P
   7 FORMAT(F6.1,4F5.1)
     ACRES=.38*HP*G*T/(H*P)
     PUNCH 5,ACRES
   5 FORMAT(F1 .2)
     STOP
     END
  25.  8 .   11.    .   1 .

C    MACH SIZE,ACRES
   1 4.5
     STOP  END OF PROGRAM AT  STATEMENT      +    LINES
```

```
C     FARM MACH REPL
      READ 5,C,A,R,SL
    5 FORMAT(F10.2,2F5.2,F5.1)
      V=C
      TC=0
      DO 20 N=1,15
      AN=N
      D=2.*(SL+1.-AN)/(SL*(SL+1.))
      R=.314*AN**1.61
      CM=C*(D+.01*R)+.[illegible]1*V*(A+[illegible]+1.[illegible])
      TC=TC+CM
      AC=TC/AN
      V=V-C*D
      PUNCH 7,AN,D,R,CM,TC,AC,V
    7 FORMAT(F5.1,6F10.2)
   20 CONTINUE
      STOP
      END
 [illegible].00  6.[illegible]  1.[illegible]  15.[illegible]
```

```
C     FARM MACH REPL
```

1.[illegible]	.13	.51	4237.8[illegible]	[illegible]	4237.80	17500.00
2.[illegible]	.12	.96	399[illegible].6[illegible]	8228.46	4114.23	15166.67
3.[illegible]	.11	1.84	3805.11	12[illegible].57	4011.1[illegible]	13000.00
4.[illegible]	.1[illegible]	2.[illegible]3	3673.[illegible]	15707.45	3926.[illegible]	11000.00
5.0	.09	4.19	3592.6[illegible]	1[illegible].17	3860.0[illegible]	[illegible]166.67
6.[illegible]	.[illegible]8	5.62	35[illegible]8.47	[illegible]	3[illegible]09.76	7500.00
7.[illegible]	.[illegible]8	7.2[illegible]	3568.[illegible]	[illegible]7.3[illegible]	377[illegible].34	6000.00
8.[illegible]	.[illegible]7	8.[illegible]	3622.[illegible]	[illegible].44	375[illegible].1[illegible]	4666.67
9.0	.[illegible]6	10.8[illegible]	3716.6[illegible]	[illegible]6.1[illegible]	3751.7[illegible]	3500.00
10.[illegible]	.[illegible]5	12.7[illegible]	3851.4[illegible]	[illegible]17.6[illegible]	3761.76	2500.00
11.[illegible]	.[illegible]4	14.91	4025.3[illegible]	41[illegible]42.[illegible]	[illegible]785.72	1666.67
12.0	.[illegible]3	17.16	42[illegible]7.4[illegible]	[illegible].37	3823.36	1000.00
13.[illegible]	.[illegible]3	19.[illegible]	448[illegible].[illegible]	[illegible]7.21	[illegible]874.40	500.00
14.[illegible]	.[illegible]2	21.[illegible]	4772.[illegible]	[illegible].1[illegible]	[illegible]	166.67
15.[illegible]	.[illegible]	24.57	5094.9[illegible]	[illegible]2[illegible]5.1[illegible]	4015.67	.00

```
      STOP   END OF PROGRAM AT  STATEMENT  [illegible]2[illegible] + [illegible]1 LINES
```

```
C  C  OPERATION COST PER HOUR
      READ 5,C,A,B,FC,W,SL,BHP,X
    5 FORMAT(F1 .2,4F5.2,2F5.1,F6.1)
      V=C
      OC=BHP*.1*(FC+W)
      DO 20 N=1,15
      AN=N
      D=2.*(SL+1.-AN)/(SL*(SL+1.))
      R=.314*AN**1.61
      CM=C*(D+.01*R)+.01*V*(A+B+1.37E)
      CH=CM/X+OC
      V=V-C*D
      PUNCH 7,AN,CH
    7 FORMAT(F5.1,F7.2)
   20 CONTINUE
      STOP
      END
 2[illegible].[illegible] 6. 1. 4. .50 15. 25. [illegible].
```

```
C  C  OPERATION COST PER HOUR
  1.   17.30
  2.   16.95
  3.   16.69
  4.   16.50
  5.   16.38
  6.   16.33
  7.   16.35
  8.   16.42
  9.   16.56
 10.   16.75
 11.   17.00
 12.   17.30
 13.   17.66
 14.   18.07
 15.   18.53
      STOP  END OF PROGRAM AT  STATEMENT [illegible] + [illegible] LINES
```

OPTIMIZATION OF POWER AND MACHINERY SELECTION FOR AGRICULTURE

by

PINNAMANENI VENKATA NARAYANA RAO

B. Sc., Andhra University, Waltair, India, 1951
D. M. I. T., Madras Institute of Technology, Madras, India, 1954

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The industrialization of a country utilizes much of its human labor and reduces muscle power available for producing food for its people. This requires the use of machines for doing farming operations. Machines can be used to increase output per person, output per acre or both. The number of operations and variety of equipment used on most farms presents machinery selection problems unlike those faced by other businesses of comparable size. In addition farm machinery use is seasonal. Total annual use may be only a few days each year. Because of these and other factors, the efficient selection of farm machinery is a tedious problem. In this paper an effort is made to investigate the least-cost method of selection of power and implement's width for a 100-acre farm in Andhra Pradesh, India.

The factors that affect the cost of using farm machinery may be divided into two groups.

I. Fixed or ownership costs, which include

(a) Depreciation

(b) Interest on investment

(c) Insurance

(d) Taxes

(e) Shelter

II. Operating costs, which include

(a) Repairs

(b) Maintenance and lubrication

(c) Fuel and oil consumption

(d) Labor

The machinery ownership costs are about the same regardless of the amount of annual use of the machine. Depreciation accounts for the larger portion of the ownership costs. For estimating the annual depreciation of a machine, one of the following methods can be used.

1. Straight-line method.
2. Declining balance method.
3. Sum of the digits method.

The straight-line method is the simplest and widely used one. The declining balance method is the constant percentage method. Sume of the digits method permits a higher rate of depreciation during the early life of a machine and depreciates it to a zero value at the end of its expected useful life.

Operating costs vary with the amount of annual use of the machine. In this item, repairs account for the major portion. Annual repair costs increase as the machine becomes old.

The equations given by Donnel R. Hunt (13) are used for investigating the least-cost method of selection of power and implement's width. The equations are (1) For the least-cost width of an implement

$$w^2 = \frac{8.25}{Fc\ \%\ p} \quad \frac{A_i}{S_i\ E_i} \sum (L_i + T_i + K_i Y_i V_i)$$

(2) For least-cost horsepower of a tractor

$$hp^2 = \sum \frac{0.022\ A_i\ ff_i}{E_i\ Fc\ \%\ t} \quad (L_i + K_i Y_i V_i) + \sum \frac{L_i}{Fc\ \%\ t} \ (1.1\ D_i W_i + G_i W_i)$$

Timeliness of machine operations is ordinarily considered as part of the more inclusive problem of machinery economics. The time available for field operations influences which machines should be selected for maximum profit, and the available time is influenced by weather conditions. The mathematical model presented by D. A. Link (19) is used for calculating the probability of completion of plowing within the time available for this purpose.

The following machinery are recommended for the typical farm under study.

1. A 35 BHP tractor . . . . one
2. A 2 x 14" mold board plow . . . . one
3. A wet land puddler of 4 ft. width . . . . . one
4. A disk harrow of 6 ft. width . . . . one
5. A seed drill for peanut of 8 ft. width . . . one
6. A spring tooth cultivator 9 8 ft. width . . one

The probability of completion of plowing came to about 99.6 per cent within three weeks time.

The computations involved in such a problem are lengthy and tedious. Hence it will be easier to write mathematical models for such problems and solve them on digital computer. Mathematical models for the following three problems are written and programmed into IBM 1620 computer.

1. Size of machine and acres it will handle.
2. Program for determining when a machine should be replaced.
3. Program for determining the cost of operation of a machine per hour.