SYSTEMS ANALYSIS APPROACH TO SELECTION OF FARM EQUIPMENT

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Farming practices in the United States have been shifting from labor intensive to relatively more capital intensive methods with simultaneous development of larger implements and more powerful tractors. In 1956, the largest general purpose farm tractor available was about 57 horsepower, but by 1969 several tractors in excess of 130 horsepower were available. Estimates by the United States Department of Agriculture indicate that by 1970 the average tractor sold will be about 80 horsepower [12, p. 40] compared with approximately 68 horsepower in 1967 [4, p. 35].

The average wholesale price of tractors has increased from $21 per horsepower in 1943 to $55 per horsepower in 1966 [14, p. 82]. However, machinery has nearly doubled the productive capacity of labor since 1954 although it has not been evident that any significant reduction in production costs has occurred [9, p. 318].

Various estimates place machinery expenses from 35 to 50 percent of total operating expenses [7, p. 24; 9, p. 304]. About one-third of non-real estate capital on farms is invested in farm machinery [9, p. 304]. Therefore, it would seem that relatively small economies obtained in selection of power and machinery systems would result in major improvements in a farmer's profit position. At the present time, there are few guidelines available to farmers to make decisions in selecting tractors and implements to form a complete farm machinery system which will minimize the annual cost of machine operations.

The primary purpose of this article is to discuss a procedure for selecting a system of power and machinery combinations for specific farm conditions. This will be accomplished by reviewing literature, presenting a theoretical concept, describing the procedure, and presenting some results.

LITERATURE

As early as 1934, attempts were made to develop systematic procedures for farm equipment selections [1]. Jeffers [6] developed a model for the identification of an optimum haying machinery system which considered unfavorable weather conditions. Several systems of haying machinery were simulated and by using probabilities of favorable working days, acres to be completed and other factors a least-cost system was identified with the mathematical tool of Lagrange multipliers.

Peart [11] has based equipment selection on a unit-flow method. A flow-chart was constructed to show feasible methods of performing the alternative processes. The flow-chart was transformed to a set of linear network equations and purchase inequalities which were solved by linear programming.

Link developed a method to select a complete set of farm machinery with a mathematical approach [8]. Profit was expressed as a function of machine widths. Equations developed for each crop were used to obtain equipment width to maximize profit. Simmons [13] and Hunt [5] revised Link's method by making it more comprehensive and flexible. Morris and Groenwald have extended the unit-flow method to a complete farm equipment system for a single enterprise and, by using linear programming, to a multiple enterprise situation [10].

LePori and Stapleton developed several systems based on different tillage activities with the assumption that each system uses the same tractor size. Equipment components were changed to be compatible with the assumed tillage activities in the production of cotton [7, p. 25].

Frisby and Bockhop have written several papers on the selection of an optimum farm machinery system

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from a set of predeveloped systems including uncertain weather factors [2, 3]. A general stochastic, activity network analysis, developed by Link, was used to determine the acreage resulting in maximum net income for a given system.

Methods for selection of machinery and power combinations have several limiting features. In general, methods developed to date require the construction of a number of complete systems, each of which must be analyzed to develop flow-charts of technically feasible equipment combinations for performing specified processes or to determine which equipment should be included in a system to meet optimum horsepower and implement characteristics.

THEORETICAL CONSIDERATIONS

A production function for crops may be stated as

$$Y = F \text{ (seed, fertilizer, cultivation practices,} \ldots \ldots \text{, land)}$$

Cultivation practices include preplant as well as postplant operations. The practices may be completed by various combinations of power and equipment as well as types of equipment. The production function may be written as

$$Y = f(X_1, X_2, \ldots, X_c, X_{c+1}, \ldots, X_{c+q}, \ldots, X_n);\ c+q < n,\quad 0 < q$$

where X_i are variable resources. The variables X_c through X_{c+q} are cultivation practices required to complete the production process. The cultivation practices can be performed by various power and implement combinations. That is, X_i ($i = c, \ldots, c+q < n$) is a function (Q_i) of alternative combinations of tractors (T) and implements (I).

$$X_i = Q_i(T_j, I_k);\quad \begin{array}{l} i = c, \ldots, c+q < n \\ j = 1, \ldots, J \\ k = 1, \ldots, K \\ 0 < q \end{array}$$

where J and K are the power and implement, respectively, requirements to perform the i^{th} cultivation practice.

Given the profit function, marginal analysis can be used to determine the optimum allocation of resources (X_i) for the least possible cost of producing the most profitable level of output. The prices and productivity of tractors and implements are considered in determining the optimum level of production and levels of resources.

Total costs (TC) for the production process are a function (G) of the resources included and the prices of the (P_{x_i}) of the resources.

$$TC = G(P_{x_1}X_1, P_{x_2}X_2, \ldots, P_{x_c}X_c, \ldots, P_{x_{c+q}}X_{c+q}, \ldots, P_{x_n}N_n)$$

However, the total costs for each cultivation practice is a function (H_i) of combinations of tractors and implements such that

$$TC_i = P_{x_i} \cdot X_i = H_i[P_{T_j}, P_{I_k}, Q_i(T_j, I_k)];\quad \begin{array}{l} i = c, \ldots, c+q < n \\ j = 1, \ldots, J \\ k = 1, \ldots, K \\ 0 < q \end{array}$$

The objective of this study was to select tractor and implement combinations such that

$$\sum_{i=c}^{c+q} H_i[P_{T_j}, P_{I_k}, Q_i(T_j, I_k)]$$

was minimized. The cultivation practices [X_i(i = c, ..., c+q)] were assumed to be predetermined.

METHOD OF SELECTION

A computer model was developed to select the power and equipment combinations that would minimize annual power and machine costs. Annual power and equipment costs included fuel, oil, maintenance, labor, interest, and depreciation. Depreciation was considered as a lump sum cost that was based on straight line depreciation schedule of 10 years.

Annual power and equipment costs were based on power and equipment prices as well as technical feasibility of the power and equipment sources. Technical feasibility was determined by draft, pull, ground speed, capacity in acres per unit of time, time requirements, and alloted time. Each tractor was capable of developing a specific drawbar pull at specified speeds and each implement had specified draft and speed requirements.

The initial basis for the computer model was the most limiting operation which was determined by the greatest power capacity requirement (Figure 1). The model began the selection with the smallest tractor and largest implement of a type which would satisfy the most limiting operation. If the tractor's drawbar pull was less than the draft requirement of the chosen implement, a smaller implement was selected. If the selected tractor did not develop sufficient drawbar pull to satisfy the requirement of any size implement of this operation type, a larger tractor was selected.

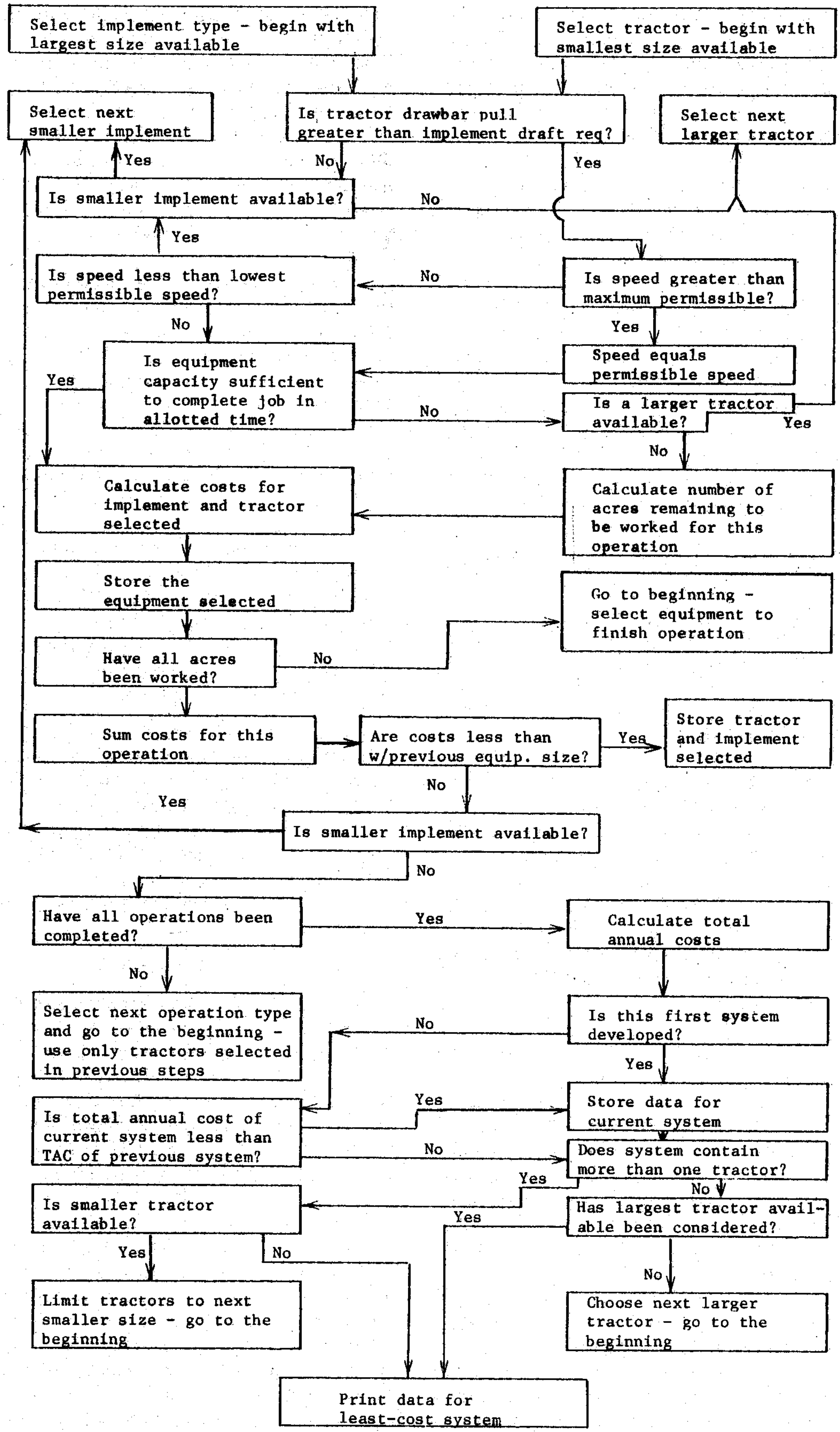

FIGURE 1. THE MODEL FOR SELECTION OF A LEAST-COST SET OF FARM MACHINERY

The tractor and implement selection was chosen to satisfy upper and lower speed requirements, also. In addition, the tractor and implement selection was required to satisfy the time allotted for the operation. For each selection which met the above requirements, fixed and variable costs were determined.

This process of selection was continued until a system capable of completing all operations had been developed. Then, other tractor and equipment sizes were evaluated to select the least-cost system.

Output of the model included the number and sizes of all tractors selected, the number and sizes of each type implement selected, hours of use, variable cost per hour and per acre associated with each implement and the rate of operation in acres per hour for each tractor and implement selection. Also, total annual variable costs of performing the operations, total investment, total annual cost, and excess capacity for each implement were included in the output.

A 960 ACRE TEXAS HIGH PLAINS FARM

Farm equipment systems were determined for a 960 acre farm in the Texas High Plains. The effects of alternative wage rates ($1.25 and $1.75 per hour) on the equipment systems were evaluated, also, the effects of various draft requirements (low and high) on the equipment systems were estimated.

Draft requirements and other input-output coefficients, as well as prices, were determined for the conditions in the Texas High Plains. Cropping patterns were determined from recent Census data. Farming practices were determined from recent research results (Table 1). This information was used to determine the least-cost, optimum four-row, optimum six-row, and optimum eight-row systems for an average 960 acre farm in the fine textured soils in the Texas High Plains.

Specification of a system, such as four-row, six-row, and eight-row, means that a planter of this size was used. An eight-row cultivator is not usually selected for use in a row crop system that has been planted with either a six-row or four-row planter. A six-row planter required selection of six-row cultivators, knife sleds, and rotary hoes. An eight-row planter does not present difficulties for four-row equipment. A least-cost system did not consider these technical problems.

Two tractors were required to complete all operations within the allotted time (Table 2). With the labor rate above $1.25 per hour, optimum eight-row systems used the second tractor in the floating operation. The second tractor was necessary for certain row crop operations with optimum six-row and four-row systems at all labor rates and with the optimum eight-row system when labor was $1.25 per hour. When the labor rate was $1.75 per hour, the optimum eight-row systems were least-cost. With labor at $1.25, the difference in total annual costs of the three different optimum row systems was less than $70 with less than $8 per year difference in the four- and six-row systems (Tables 3, 4 and 5). With an upward trend in labor rates, an eight-row system would generally be the preferred system.

Lowering the draft requirements of implements reduced total annual costs. At a given wage rate, the difference in annual costs from low draft to high draft requirements for a particular row system was greater than the range between the least-cost and other optimum row systems under the high draft assumption. That is, on the 960 acre farm, changes in draft requirements had more effect on total annual costs than did changes in the optimum row system used. As draft requirements were lowered, larger equipment gained in relative cost advantage; i.e., as draft requirements were lowered, total annual costs for optimum four-row systems and for optimum eight-row systems decreased, but the percent decrease was larger for optimum eight-row systems. The difference in total annual costs for optimum four-, six-, and eight-row systems was greater in low draft situations than in high draft situations.

As draft requirements increased, variable costs and total annual costs were increased. System investment varied directly with level of draft requirement. At $1.75 per hour labor when draft requirements were increased from low to high, the investment in the least-cost system increased by $3,506. Increasing draft requirements from low to high resulted in a change in system investment for all systems for both labor rates.

SUMMARY

The method has several advantages. It may be used for any selected farm situation where prices and input-output coefficients are available for draft, pull, cropping patterns and cultivation. It also evaluates various sources of power and types of technically feasible equipment, and, although timeliness coefficients and probabilities of working days were not included, the procedure can be modified to include these considerations. It can be used to determine equipment combinations that will provide guidelines for new equipment outlays. Thus, equipment dealers could provide consultant services to customers with this method of analysis. It can also be used as a linear programming subroutine. At present, activities in a linear programming problem include predetermined power and equipment combinations, while this procedure would also provide selection of power and equipment combinations as well as the most profitable enterprises for the farm plan.

TABLE 1. OPERATIONS REQUIRED FOR A 960 ACRE FARM, TEXAS HIGH PLAINS, 1969[a]

Operation	Times over each acre[b]					Total acres for each operation
	Grain Sorghum	Cotton	Wheat	Other Crops	Diverted Cropland	
Shred	1.00	1.00	----	1.00	----	593.4
Break	0.25	0.25	0.5	0.25	----	203.48
Tandem	2.00	2.00	3.0	2.00	3.0	2241.5
Chisel	1.00	1.00	2.0	1.00	1.0	1055.6
Float	2.00	2.00	1.0	2.00	----	1297.3
List	1.00	1.00	----	1.00	----	593.4
Ditch	----	----	----	----	----	9.5
Rotary Hoe	1.00	1.50	----	1.50	----	846.1
Plant	1.25	1.25	----	1.25	----	1587.8
Knife	1.00	0.50	----	0.50	----	440.8
Sandfight	1.50	1.50	1.5	1.50	1.5	1417.5
Cultivate	2.00	3.00	----	3.00	----	1492.1
Drill	----	----	1.0	----	----	110.6

[a]The estimates were determined from Madden, J. Patrick and Bob Davis, "Economies of Size on Irrigated Cotton Farms of the Texas High Plains," TAES Bulletin B-1037.

[b]The 960 acre farm included 288.1 acres of grain sorghum, 239.1 acres of cotton, 110.6 acres of wheat, 66.2 acres of other crops, and 241 acres of diverted cropland.

TABLE 2. LEAST-COST EQUIPMENT SYSTEM FOR 960 ACRE FARM WITH LABOR AT $1.25 PER

Item	Units	Size	Hours of Use
Tractor	Horsepower	102	1205.5
		37	178.7
Float	Feet	12	200.0
		9	100.9
Breaking Plow	16" Bottoms	3	113.4
Tandem Disc	feet	20	231.4
Lister-Planter	Row	6	137.8
Chisel	Feet	13	172.1
Shredder	Row	4	61.3
Cultivator	Row	6	150.0
		4	77.8
Rotary Hoe	Row	8	40.8
Knife Sled	Row	8	51.9
Sandfighter	Row	18	11.3
Grain Drill	Feet	13	27.0
V-Ditcher	Unit	1	8.5

TABLE 3. ANNUAL VARIABLE COSTS FOR 960 ACRE FARM FOR LEAST-COST, FOUR-ROW, SIX-ROW, AND EIGHT-ROW SYSTEMS FOR TWO LABOR RATES AND TWO DRAFT REQUIREMENTS, TEXAS HIGH PLAINS, 1969

System	Labor Rate per Hour	
	$1.25	$1.75
	Low Draft Requirements	
Least-Cost	4152.58	4685.60
Four-Row	4687.78	5432.61
Six-Row	4355.27	5015.32
Eight-Row	4086.75	4685.60
	High Draft Requirements	
Least-Cost	4884.70	5486.51
Four-Row	5348.17	6173.67
Six-Row	4941.71	5330.82
Eight-Row	4867.12	5400.60

TABLE 4. ANNUAL COSTS FOR 960 ACRE FARM FOR LEAST-COST, FOUR-ROW, SIX-ROW, AND EIGHT-ROW SYSTEMS FOR TWO LABOR RATES AND TWO DRAFT REQUIREMENTS, TEXAS HIGH PLAINS, 1969

System	Labor Rate per Hour	
	$1.25	$1.75
	Low Draft Requirements	
Least-Cost	6979.58	7590.34
Four-Row	7460.17	8205.00
Six-Row	7352.40	8012.46
Eight-Row	6991.49	7590.34
	High Draft Requirements	
Least-Cost	7835.67	8520.52
Four-Row	8150.62	9016.09
Six-Row	8199.18	8849.79
Eight-Row	8142.71	8755.86

TABLE 5. SYSTEM INVESTMENT FOR 960 ACRE FARM FOR LEAST-COST, FOUR-ROW, SIX-ROW, AND EIGHT-ROW FOR TWO LABOR RATES AND TWO DRAFT REQUIREMENTS, TEXAS HIGH PLAINS, 1969

System	Labor Rate per Hour	
	$1.25	$1.75
	Low Draft Requirements	
Least-Cost	22,000	22,605
Four-Row	21,575	21,575
Six-Row	23,324	23,324
Eight-Row	22,605	22,605
	High Draft Requirements	
Least-Cost	23,276	23,611
Four-Row	21,809	22,120
Six-Row	25,350	27,385
Eight-Row	25,491	26,111

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