AN INTRODUCTORY ANALYSIS OF THE BASIC PHYSICAL AND COST RELATIONSHIPS INVOLVED IN OWNING AND OPERATING TRACTORS AND TILLAGE EQUIPMENT

by

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CHAPTER I

INTRODUCTION

Estimates of agricultural machinery ownership and operation costs are a portion of the information inputs used in the decision-making processes in agriculture. However, most cost data presently available exhibit certain deficiencies as listed below.

A single type of equipment may often be used for a variety of purposes, under various physical conditions, and with differing degrees of care and maintenance. Therefore, it is difficult to obtain a cost estimate for any particular area or situation. Most cost estimates are of three types. The first type, single-valued estimates of variable costs, have been derived from controlled experiments under a specific set of conditions. Because of the expense involved, only a few of the many thousand possible combinations of conditions actually encountered in the field have been explored. Therefore, such data are rarely applicable to an actual farming situation.[1] The second type, single-valued

[1] For examples of the type of basic data from which such machinery costs are derived, see Dept. of Agr. Eng., Nebraska Tractor Test Reports, Univ. of Nebr., Lincoln, periodical release or The American Society of Agricultural Engineers, Agricultural Engineers Yearbook, St. Joseph, annually.

estimates of variable costs, have been derived from interviews with many farm machinery owners. Often, the estimate is an average or a modal value of many cost observations. Since each cost observation was generated under differing conditions the average or modal cost has very little meaning. If each observation was generated under similar conditions, the resulting estimate has the same deficiencies as if it were derived from a controlled experiment, that is, the estimate is not generally applicable.[1] The third type, ownership costs (depreciation and interest on invested capital), have often been computed using rather arbitrary estimates of total length of life and standard "income tax type" depreciation including the straight line, declining balance, and sum of year's digits methods. While these estimates may be useful for tax purposes, or for illustration of computational methods, they do not represent the true opportunity cost of a machine to the owner. Actual depreciation as well as interest on invested capital is related to actual market value. If market value is a function of variables such as total hourly use or state of repair, then standard depreciation schedules do not give satisfactory cost estimates.

This report presents the results of a preliminary analysis involved in an attempt to develop multiple-valued cost estimates--the

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[1] Single-valued estimates derived from observations created under differing conditions may be quite useful if the variance of the estimate is small. That is, if the various combinations of use do not appreciably change costs.

particular value depending on the size and type of equipment, and the variety of conditions under which this equipment is bought, sold, and used. There are no published reports on machinery cost analysis using a similar methodology.

Objectives and Methodology

The general long-range objective of this area of study is to develop a system of multiple regression equations in order to estimate each component of machinery ownership and operation cost for the many machines and machinery combinations. In view of the number of machinery combinations used in divergent areas under differing conditions, the magnitude of the undertaking is large. Even by using high speed computers for processing the hypothesized equations, the time and effort involved as well as the expense would be very great.

This study reports the results of a preliminary analysis with three specific objectives. First, it checks the reliability of cost data collected by the farm survey method. As noted, cost data of this type exhibit wide variance. If these data are reliable this variance can be explained by correlation and/or regression analysis. If the variance cannot be explained, the farm survey method of obtaining cost data becomes suspect. Secondly, it uses available data to select relevant variables from among those variables hypothesized as effecting costs.

If the more relevant variables can be so selected, the time and expense involved in formulating and testing alternative regression models may be greatly reduced. In addition, the researcher has a better idea of the type of data necessary for further analysis. Finally, this study serves as a guide with respect to the amount of data and the time required for collecting the requisite data needed for adequate regression analysis.

Methodology

Correlation analysis was employed to determine which of the hypothesized variables were influential in each cost determination.[1] Each independent variable was tested to discover its simple correlation with the dependent variable rather than formulate many alternative sets of complete equations. Using this method, many variables may be tested, while only those with high simple correlation coefficient (r values) would be included in the formulations used for regression analysis. Experience has shown that the r value between the independent and dependent variables should usually be .50 or higher before the

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[1] For a complete summary of correlation analysis see: Ezekiel, Mordecai, Methods of Correlation Analysis, John Wiley and Sons, Inc., New York, 1953. Also, Pearson, Frank A. and Kenneth B. Bennett, Statistical Methods, John Wiley and Sons, Inc., New York, 1951, pp. 193-195.

correlation can be a useful relationship.[1] The per cent of the variance in the dependent variable explained by the variance in the independent variable is given by r^2 (the coefficient of determination). For example, a correlation (an r value) of .90 explains 81 per cent of the variation in the observed relationship; an r of .50 or less explains 25 per cent or less of the observed variation.

If each of two or more independent variables are correlated with a single dependent variable, a multiple regression formulation may be obtained. Here, the variance of the dependent variable is explained by the combined relationships with all of the independent variables. A multiple coefficient of determination (R^2) expresses the percentage of variance so explained.

The multiple R^2 is equal to the sum of the simple r^2's only if each of the independent variables are uncorrelated with the other. This is rarely the case. Thus, the cross-correlation between independent variables was computed as well as the correlation between the dependent and independent variables. Here, experience has shown that if two independent variables have a cross-correlation of .50 or higher the

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[1] This rule of thumb was obtained from Dr. Henry Tucker, Agricultural Statistician, University of Arizona, Tucson, in a personal interview.

inclusion of both of these variables in a multiple regression analysis usually[1] would be superfluous.

The exact relationship between the simple correlation coefficients and a multiple coefficient of determination may be expressed for the two-independent-variable case as follows:

Let y equal the dependent variable, x_1 and x_2 equal the independent variables, and r_{yx_1} equal the correlation between the variables y and x_1, then

$$R^2_{y.x_1x_2} = \frac{r^2_{yx_1} + r^2_{yx_2} - 2r_{yx_1} r_{yx_2} r_{x_1x_2}}{1 - r^2_{x_1x_2}}$$

For example, assume that two variables hypothesized as being related to the variance of the dependent variable have r values of .80 and .70. The intercorrelation between these two variables is .40. The variables taken separately explain 64 per cent and 49 per cent, respectively, of the variance in the dependent variable. A multiple regression analysis, analyzing the combined explanation of these two variables, would show that 81 per cent of the total variance was explained.[2] Had the

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[1] The exception is when each of the independent variable's correlation with the dependent variable is very high--that is, approaching a value of 1.00.

[2] $R^2_{y.x_1x_2} = \frac{.64 + .49 - 2(.80)(.70)(.40)}{1 - .16} = .81$

intercorrelation coefficient been .90, the inclusion of the second variable in the analysis would be superfluous. The $R^2_{y.x_1x_2}$ would be .643, a gain of only .003 over the value of the highest simple r^2.

The variables hypothesized for each component cost estimate were treated in the afore described manner. Some variables believed to contribute to various explanations were necessarily omitted due to the lack of data or inadequate means of quantification. Those variables for which seemingly adequate data were available were tested and the results are recorded and discussed in Chapter II. Definitions of these variables and the relationships actually subjected to empirical analysis are presented in Appendices A and B.

Source of Data

Data for this study were collected by personal interview with Arizona farmers and ranchers in late 1960 and early 1961. Answers were farmer's estimates or were from the farmer's memory. Little information was obtained directly from records.

The sample frame consisted of County Agricultural Stabilization and Conservation Committee lists of farms and ranches with cotton allotments in the four Arizona counties of Maricopa, Pima, Pinal, and Yuma. This listing was selected to insure that plowing and/or disking operations would be common to the entire sample.

Farms were stratified by total cropland acres as listed by the ASC. From this stratified frame, a random proportionate sample[1] was drawn. Proportionate sampling was followed to compensate for the wide variance in total number of farms in the different strata. For this particular study stratification by farm size was not necessary. Stratification by machinery size or type would have been more relevant. Stratification by farm size was done so that data would be applicable for other studies involving economies of size. However, the stratification was useful for the present study insofar as machinery size is correlated with farm size. The schedules used (see copies in Appendix C) were not designed with the particular type of analysis used in this study in mind; rather this study used the data as the best available.

Schedules were obtained for 161 tractors, 125 plows, 138 disks, and 263 machinery combinations on 146 farms. Approximately 450 man hours of interview labor was expended. All farms for which schedules were taken were irrigated and had cotton allotments. With the exception of these two similarities there was wide variance in the type of operation, type of operator, enterprise combinations, and level of management.

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[1] Spurr, William A., Lester S. Kellogg, and John H. Smith, Business and Economic Statistics, Richard D. Irwin, Inc., Homewood, Illinois, 1955, pp. 98-99.

CHAPTER II

THE COST ANALYSIS

Machinery costs are usually classified into two groups for economic analysis--variable costs and fixed costs. Variable costs are those costs that vary with use. If the machine is not used, the cost is not incurred. Estimates of variable costs may thus be made on a per unit of work basis. In this study the hour is used. Cost per acre would be another possibility. Fixed costs are those costs associated with ownership. Depreciation, interest on investment, taxes, and insurance are prime examples of costs which are usually considered fixed. These costs are presumably incurred whether or not the machine is used. Cost per year is used as the unit of measure for fixed costs. It is recognized that a portion of the decline in market value over time (depreciation) may be associated with wear due to use. If this is true a portion of depreciation, and, consequently, a portion of interest on investment, becomes a variable cost. This hypothesis is tested in this study.

In the following analysis each of the variable and fixed cost components are examined in detail. In each case a theoretical model

is hypothesized. Then the results of a preliminary test of this hypothesis are presented.

Estimates Relating to Variable Costs

Field Capacity

Field capacity is defined as the amount of work accomplished by a farm machine in a given unit of time--in this case acres covered per hour. Acres per hour required to perform a given operation must be known in order to compute labor requirements, machinery requirements, and, in combination with costs per hour, variable costs per acre. The following relationships were hypothesized for the field capacity of tractors pulling either a plow or a disk. All following hypotheses consider each relationship under conditions of ceteris paribus--that is, all other things being equal.

As drawbar horsepower increases given a particular size of tillage equipment, the speed of the operation would increase due to the ability to operate in a higher gear. As depth of tillage is increased, all other factors held constant, field capacity would decrease as it becomes necessary to operate in a lower gear.

Total width of cut may affect field capacity in two ways. Increased width will slow down a given tractor in speed; however, fewer runs per acre are then necessary to cover the land. The net effect on field capacity

may either be positive or negative, unless tractor speed is held constant. Increasing the length of run will increase field capacity because fewer turns are necessary per acre. Heavy soil will provide more draft than will light soils; sod will provide more draft than nonsod. Finally, the tractor's actual performance per rated drawbar horsepower will decline as the condition of the tractor becomes poorer.

No data were available on condition of tractors and too little data were available on previous crop or crop residue. Therefore, the validity of these two relationships on field capacity were not tested. Simple correlation and cross-correlation coefficients were computed between the dependent variable, acres per hour, and the following independent variables--maximum drawbar horsepower[1], depth of tillage operation, and width of equipment--for groups of data classified by tractor type and soil type. Results of this correlation analysis are shown below. The functional relationships implicityly hypothesized by the above discussion are listed in Appendix B.

Field Capacities for Wheel Tractors Plowing and Disking--Drawbar horsepower is the most highly correlated variable relating to field capacity while plowing (Table 1). Forty-five per cent, 53 per cent,

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[1] For definition see "Implement and Tractor," Red Tractor Book, Kansas City, Missouri, 1958, p. 487.

Table 1. Simple Correlation Coefficients Relating to Acres per Hour for Wheel Tractors Plowing in Different Soil Textures.

Variable	Desig-nation of Variable	Drawbar Horse-power X_1	Depth of Tillage X_{22}	Total Width of Equipment X_{23}
		Light Soil (29 Observations)		
Acres per hour	Y_1	.67	-.17	.05
Drawbar horsepower	X_1		.16	.12
Depth of tillage	X_{22}			.49
Total width of equipment	X_{23}			
		Medium Soil (9 Observations)		
Acres per hour	Y_2	.73	.34	.87
Drawbar horsepower	X_1		.71	.90
Depth of Tillage	X_{22}			.52
Total width of equipment	X_{23}			
		Heavy Soil (5 Observations)		
Acres per hour	Y_3	.71	-.61	.09
Drawbar horsepower	X_1		-.41	-.29
Depth of Tillage	X_{22}			.01
Total width of equipment	X_{23}			
		All Soils (44 Observations)		
Acres per hour	Y_4	.65	-.06	.01
Drawbar horsepower	X_1		.38	.15
Depth of tillage	X_{22}			.39
Total width of equipment	X_{23}			

and 50 per cent of the variance in plowing field capacities were explained by tractor horsepower in the light, medium, and heavy soils, respectively.[1] When soil type is disregarded, only 42 per cent of the variance is explained. Evidently, soil type is also a relevant variable.

Results were mixed when horsepower and disking field capacity were correlated (Table 2). Relatively large positive coefficients appear for the light soil, medium soil, and all soil classifications, but the coefficient is negative for the heavy soil classification. However, the heavy soil classification was small, containing only five observations. A single erroneous observation could have masked the true correlation.

The coefficients relating depth to field capacity were also of mixed size and sign for plowing and disking. Under the hypothesis, the coefficients would be negative, that is, as depth increases, field capacity would decrease. A large negative coefficient was obtained for plowing in heavy soil. However, where all soil types are considered, the effect of depth seems to be masked. The width-field capacity coefficients are high and positive where width and horsepower are highly correlated and are low or negative where width and horsepower are relatively uncorrelated or negatively correlated. Thus, it appears that a width variable alone would add very little to an explanation of field

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[1] Data in Tables 1 through 25 are r_{ij} values, that is, simple correlation coefficients. A coefficient of determination, r^2_{ij}, shows the per cent variance in variable i explained by correlating it with variable j.

Table 2. Simple Correlation Coefficients Relating to Acres per Hour for Wheel Tractors Disking in Different Soil Textures.

Variable	Designation of Variable	Drawbar Horsepower X_1	Depth of Tillage X_{22}	Total Width of Equipment X_{23}
	Light Soil (31 Observations)			
Acres per hour	Y_5	.74	.33	.68
Drawbar horsepower	X_1		.38	.63
Depth of tillage	X_{22}			.45
Total width of equipment	X_{23}			
	Medium Soil (13 Observations)			
Acres per hour	Y_6	.33	-.11	.52
Drawbar horsepower	X_1		-.10	.89
Depth of tillage	X_{22}			.04
Total width of equipment	X_{23}			
	Heavy Soil (5 Observations)			
Acres per hour	Y_7	-.42	-.14	-.18
Drawbar horsepower	X_1		-.58	-.71
Depth of tillage	X_{22}			.79
Total width of equipment	X_{23}			
	All Soils (50 Observations)			
Acres per hour	Y_8	.57	.28	.63
Drawbar horsepower	X_1		.24	.70
Depth of tillage	X_{22}			.38
Total width of equipment	X_{23}			

capacity variance. Evidently, tractor speeds are decreased just enough to offset increased width if width is increased without a corresponding increase in horsepower.

Field Capacities for Crawler Tractors Plowing and Disking--Neither horsepower, depth of tillage, nor width of equipment showed notable correlation with crawler field capacity while plowing or disking (Tables 3 and 4). If the data were reliable the lack of correlation between field capacity and horsepower and field capacity and depth would indicate that the crawler tractors in the sample possessed appreciable amounts of surplus power. However, if surplus power were available, surely field capacity and width would be correlated. If no decrease in speed is necessary as width is increased, field capacity must go up. Since width and field capacity were uncorrelated, it must be concluded that the data were not reliable.

Fuel Consumption

In order to estimate the cost of fuel per hour of operation, fuel consumption per hour must first be known. Cost per hour is then computed as gallons per hour times cost per gallon. Given a particular type tractor (e.g., wheel tractor using gasoline), the variables hypothesized as influencing consumption per hour are (1) drawbar horsepower of tractor, (2) tractor's general state of repair, (3) quantity and quality of day-to-day care the tractor received, (4) depth of tillage operation,

Table 3. Simple Correlation Coefficients Relating to Acres per Hour for Crawler Tractors Plowing in Different Soil Textures.

Variable	Designation of Variable	Drawbar Horsepower X_1	Depth of Tillage X_{22}	Total Width of Equipment X_{23}
	Light Soil (42 Observations)			
Acres per hour	Y_9	.29	-.10	.18
Drawbar horsepower	X_1		.34	-.19
Depth of tillage	X_{22}			-.13
Total width of equipment	X_{23}			
	Medium Soil (13 Observations)			
Acres per hour	Y_{10}	.03	.04	.13
Drawbar horsepower	X_1		.75	.65
Depth of tillage	X_{22}			.62
Total width of equipment	X_{23}			
	Heavy Soil (10 Observations)			
Acres per hour	Y_{11}	.15	.07	.36
Drawbar horsepower	X_1		-.07	-.17
Depth of tillage	X_{22}			.46
Total width of equipment	X_{23}			
	All Soils (67 Observations)			
Acres per hour	Y_{12}	.23	-.01	.20
Drawbar horsepower	X_1		.36	-.04
Depth of Tillage	X_{22}			.14
Total width of equipment	X_{23}			

Table 4. Simple Correlation Coefficients Relating to Acres per Hour for Crawler Tractors Disking in Different Soil Textures.

Variable	Desig-nation of Variable	Drawbar Horse-power X_1	Depth of Tillage X_{22}	Total Width of Equipment X_{23}
	Light Soil (40 Observations)			
Acres per hour	Y_{13}	.39	-.06	.44
Drawbar horsepower	X_1		-.01	.72
Depth of tillage	X_{22}			.05
Total width of equipment	X_{23}			
	Medium Soil (14 Observations)			
Acres per hour	Y_{14}	.48	-.41	.39
Drawbar horsepower	X_1		-.25	.84
Depth of tillage	X_{22}			-.28
Total width of equipment	X_{23}			
	Heavy Soil (9 Observations)			
Acres per hour	Y_{15}	.26	.39	.28
Drawbar horsepower	X_1		.17	.49
Depth of tillage	X_{22}			.30
Total width of equipment	X_{23}			
	All Soils (65 Observations)			
Acres per hour	Y_{16}	.37	-.01	.40
Drawbar horsepower	X_1		-.02	.72
Depth of tillage	X_{22}			.06
Total width of equipment	X_{23}			

(5) total width of tillage equipment, (6) speed at which tractor is operated, and (7) the type and condition of the soil on which the tractor works.

Fuel consumption is a function of generated horsepower. As generated horsepower increases, fuel consumption increases.[1] As horsepower is increased, motor size also increases. An increase in motor size is accompanied by an increase in total tractor weight. The total weight increase is attributable to increased motor weight plus a proportional increase in over-all tractor size and/or strength to facilitate utilization of increased power. Thus, as total weight and engine size increase, fuel consumption necessary to run the tractor without performing any work increases. For this reason fuel consumption will rise as rated maximum horsepower rises, all other things being constant.

Fuel consumption would be lower if a tractor is in a good state of repair than if in a poor state of repair. In fact, fuel efficiency is one of the main reasons for repairing worn equipment. Repairs such as spark plugs, fuel injectors, etc., would be good examples of the type of repairs which would contribute to a decrease in fuel consumed. Data were not available on the tractor's general state of repair. Therefore, in the empirical model it was assumed that the repair cost in

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[1] Department of Agricultural Engineering, Nebraska Tractor Test Reports, University of Nebraska, Lincoln, years 1940-1961.

year Y would be an index of a tractor's state of repair in year Y. The assumption was that the greater the repair cost, the better state of repair the tractor would be in. Therefore, fuel consumption and repair cost would be negatively correlated.

By the quality and quantity of day-to-day care is meant such practices as regular servicing of the air cleaner, cleaning and adjusting spark plugs, adjusting fuel injectors, etc. These services are performed to promote efficient operation. It was assumed that the amount of time spent on such servicing practices per hour of tractor operation would serve as an index of care. Thus, service time and fuel consumption should be negatively correlated.

Both depth of tillage and width of equipment are hypothesized to increase fuel consumption as depth or width is increased. This is due to the increased draft on the given tractor. Thus, positive correlations with fuel consumption were expected.

The speed at which a tractor is operated will influence fuel consumption. Data were not available in miles per hour, so acres per hour were used as an index of speed. Presumably, there is an optimum speed for most efficient operation. Fuel consumption per hour will increase for speeds both higher and lower than this optimum speed. Type of soil (heavy, medium, or light) and previous crop (sod or non-sod) both influence fuel consumption due to changes in draft. Heavier

soils and sod coverage contribute to higher fuel consumption as opposed to lighter soils and no residual cover.

Components of the functional relationships implicitly hypothesized above were tested for empirical relevance. Results of this analysis follow. These relationships are listed in Appendix B as Y_{17} to Y_{24}.

Fuel Consumption for Gasoline Wheel Tractors Plowing and Disking--On first inspection repairs in year Y appeared to be a relevant variable for both plowing and disking in explaining the fuel use variance (Table 5). When plowing, 66 per cent of the variance in fuel use is explained by repairs in year Y and when disking, 26 per cent of the variance is explained by repairs. However, the sign of the coefficient should be negative rather than positive under the hypothesis that repairs increase as fuel consumption decreases. The correlation could be either positive or negative depending on the point in time when the observation of fuel consumption was incurred. If the repairs occurred after an increase in fuel consumption was experienced, the correlation would be positive. But if the repairs were made before the observation on fuel consumption was taken, a negative correlation would result. Therefore, the consumption rate needs to be identified as to whether it refers to the consumption before or after repairs in order to formulate an acceptable hypothesis. Data were not available to do this.

Table 5. Simple Correlation Coefficients Relating to Fuel Consumption per Hour for Gasoline Wheel Tractors Plowing and Disking.

Variable	Designation of Variable	Drawbar Horsepower X_1	Repairs in Year Y X_6	Service Time per Hour X_7	Depth of Tillage X_{22}	Total Width of Equipment X_{23}	Acres per Hour X_{24}
			Plowing (17 Observations)				
Fuel consumption	Y_{17}	.66	.81	.36	-.08	.27	.70
Drawbar horsepower	X_1		.40	.32	.30	.28	.45
Repairs in year Y	X_6			.35	-.14	.19	.39
Service time per hour	X_7				.27	.15	.22
Depth of tillage	X_{22}					.44	-.01
Total width of equipment	X_{23}						.16
Acres per hour	X_{24}						
			Disking (22 Observations)				
Fuel consumption	Y_{18}	.46	.51	.41	-.24	.30	.51
Drawbar horsepower	X_1		.05	.44	-.07	.65	.46
Repairs in year Y	X_6			.44	.01	.48	.54
Service time per hour	X_7				.13	.64	.37
Depth of tillage	X_{22}					-.11	-.15
Total width of equipment	X_{23}						.61
Acres per hour	X_{24}						

Two other variables, acres per hour and horsepower, show relatively large influence on fuel consumption. It was hypothesized that as acres per hour or horsepower increases, fuel consumption increases. The positive sign supports this hypothesis in both instances. Acres per hour explains 49 per cent of the variance when plowing and 26 per cent when disking. Drawbar horsepower explains 44 per cent of the variance when plowing and 21 per cent when disking. The cross-correlation between acres per hour and horsepower is low enough to warrant the inclusion of both variables in the relationship. One reason for more explanation in the case of plowing is the association of more draft encountered with the plowing operation, thus a higher power requirement. There is more variance in the draft requirement when plowing than when disking.

Fuel Consumption for Diesel Wheel Tractors Plowing and Disking--Service time appears to be the only relevant variable for both plowing and disking (Table 6). Thirty-two per cent of the fuel consumption variance is explained by service time when plowing and 30 per cent is explained when disking. Apparently, servicing is an important practice in diesel tractor maintenance; thus, as more service time is used, fuel consumption decreases. Repairs in year Y is a promising variable when disking, explaining 27 per cent of the fuel variance. The negative sign of the coefficients means that as service time and repairs are less,

Table 6. Simple Correlation Coefficients Relating to Fuel Consumption per Hour for Diesel Wheel Tractors Plowing and Disking.

Variable	Designation of Variable	Drawbar Horsepower X_1	Repairs in Year Y X_6	Service Time per Hour X_7	Depth of Tillage X_{22}	Total Width of Equipment X_{23}	Acres per Hour X_{24}
			Plowing (14 Observations)				
Fuel consumption	Y_{19}	.00	-.46	-.57	.26	-.15	-.16
Drawbar horsepower	X_1		.74	.19	.37	.14	.80
Repairs in year Y	X_6			.45	-.10	-.08	.76
Service time per hour	X_7				-.24	-.05	.27
Depth of tillage	X_{22}					.50	-.09
Total width of equipment	X_{23}						-.02
Acres per hour	X_{24}						
			Disking (16 Observations)				
Fuel consumption	Y_{20}	-.06	-.52	-.55	-.41	-.25	-.34
Drawbar horsepower	X_1		.73	.16	.28	.79	.54
Repairs in year Y	X_6			.45	.41	.56	.68
Service time per hour	X_7				.31	.24	.22
Depth of tillage	X_{22}					.52	.48
Total width of equipment	X_{23}						.65
Acres per hour	X_{24}						

fuel consumption will increase. Tractor horsepower in this category showed no influence on fuel consumption which indicates that the tractors had power in surplus of that needed for plowing and disking. No logical explanation can be offered as to why the repairs in year Y coefficient had the right sign when considering crawler tractors and the wrong sign for wheel tractors. Differing results must be due to chance in how the data were obtained, as explained in the above discussion of gasoline tractors.

Fuel Consumption for Crawler Tractors[1] Plowing and Disking--Drawbar horsepower is a relevant variable for both plowing and disking. Forty-one per cent of the fuel variance is associated with horsepower when plowing and 35 per cent when disking (Table 7). The low coefficient value for acres per hour when plowing suggests that plowing is a more constant operation with less variance than disking. That is, the speed of plowing is relatively constant, whereas the speed of disking is subject to a wider speed variance.

All other variables tried had mixed signs and values; thus, little can be concluded concerning their influence on fuel consumption.

Fuel Consumption for All Diesel Tractors Plowing and Disking--When all diesel tractors are combined, drawbar horsepower is the only

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[1] All crawler tractors had diesel burning engines.

Table 7. Simple Correlation Coefficients Relating to Fuel Consumption per Hour for Crawler Tractors Plowing and Disking.

Variable	Designation of Variable	Drawbar Horsepower X_1	Repairs in Year Y X_6	Service Time per Hour X_7	Depth of Tillage X_{22}	Total Width of Equipment X_{23}	Acres per Hour X_{24}
			Plowing (59 Observations)				
Fuel consumption (diesel)	Y_{21}	.64	.13	-.07	.26	-.03	.14
Drawbar horsepower	X_1		.18	.10	.38	-.09	.15
Repairs in year Y	X_6			.17	-.01	-.26	-.19
Service time per hour	X_7				-.26	-.14	-.14
Depth of tillage	X_{22}					.19	-.08
Total width of equipment	X_{23}						.25
Acres per hour	X_{24}						
			Disking (57 Observations)				
Fuel consumption (diesel)	Y_{22}	.59	.24	.05	.20	.46	.53
Drawbar horsepower	X_1		.31	.17	-.04	.70	.42
Repairs in year Y	X_6			.21	.04	.29	.08
Service time per hour	X_7				-.09	.04	-.11
Depth of tillage	X_{22}					.06	.01
Total width of equipment	X_{23}						.42
Acres per hour	X_{24}						

notable variable, explaining 32 per cent and 26 per cent of the variance in fuel consumption when plowing and disking, respectively (Table 8).

Results for the other variables were mixed and were not similar between plowing and disking. It was hypothesized that by combining all diesel tractors, better results might be obtained than with the individual classes. This would be true if there were not enough variance within the individual classes and the class distinctions had no real meaning. If the class distinctions had meaning, then the expected results would be poorer. Poorer results were obtained in this case.

Cost of Oil and Grease for Tractors and Implements

Many independent variables are thought to influence the cost of oil and grease used by tractors, plows, and disks. Some were quantifiable; others could not be quantified per se. Those variables which were not quantified include (1) tractor crankcase capacity, (2) differences in time between servicing, (3) type of lubricant used, (4) the conditions of sale, i.e., the reflection of price discounts, and (5) the total amount of oil and grease used in a given time.

Variables tested for correlation with oil and grease costs for tractors are (1) drawbar horsepower, (2) model year of machine, (3) repairs in year Y, (4) service time per hour of operation, (5) price of oil, and (6) price of grease. For plows and disks, size of equipment

Table 8. Simple Correlation Coefficients Relating to Fuel Consumption per Hour for All Diesel Tractors Plowing and Disking.

Variable	Designation of Variable	Drawbar Horsepower X_1	Repairs in Year Y X_6	Service Time per Hour X_7	Depth of Tillage X_{22}	Total Width of Equipment X_{23}	Acres per Hour X_{24}
			Plowing (73 Observations)				
Fuel consumption	Y_{23}	.57	.29	.00	.41	.17	.23
Drawbar horsepower	X_1		.28	.16	.45	.08	.41
Repairs in year Y	X_6			.20	.11	-.13	-.04
Service time per hour	X_7				-.19	-.08	-.03
Depth of tillage	X_{22}					.32	.02
Total width of equipment	X_{23}						.27
Acres per hour	X_{24}						
			Disking (73 Observations)				
Fuel consumption	Y_{24}	.51	.35	.07	.11	.54	.30
Drawbar horsepower	X_1		.35	.19	.07	.75	.47
Repairs in year Y	X_6			.24	.06	.37	.12
Service time per hour	X_7				.00	.15	.00
Depth of tillage	X_{22}					.18	.17
Total width of equipment	X_{23}						.47
Acres per hour	X_{24}						

is used in place of tractor drawbar horsepower. Separate cost estimates were formulated for tractors and plows and disks.

Assuming regular servicing, oil consumption is a function of horsepower. As horsepower is increased, crankcase capacity increases, thus the amount of oil used is greater within a given time period. Newer model tractors are designed so that less, or no regular greasing, is required. For this reason the amount of grease used would be negatively correlated or uncorrelated to age.

Repairs in year Y was used again as an index to indicate condition. A tractor in poor mechanical repair would use more oil and grease than a comparable model in good mechanical condition. Service time is also an index of general tractor condition. Condition would deteriorate as service time is decreased, thus increasing oil consumption.

Price per unit of oil and grease presumably is related to quality. Higher priced products are represented as possessing higher quality than lower priced products. Thus, the use of higher priced products would decrease wear which in turn reduces consumption. Whether the decrease in consumption would offset the higher cost incurred is not known. It is obvious that higher prices push costs upward.

The cost of oil and grease used in a given time period would be a function of the total oil and grease used in that period. The cost

would increase proportionately as increased amounts of lubricants are used. The main reason for including type of lubricant, in addition to price, is to reduce variance in price of specific types due to bulk purchase or quantity discounts.

No data were available for type of lubricant used nor for total quantity used in a given time period. Crankcase capacities were available along with time (hours) between oil changes and greasing. However, no data as to how much oil or how much grease was used between regular service periods were obtained.

Implement considerations involve the variable size in place of tractor horsepower. The lubrication requirement would increase as size of plow or disk is increased. For example, with a moldboard plow, a certain amount of grease is required for each moldboard. Thus, as additional moldboards are employed, grease requirements will increase proportionately. In the case of disks, as width is increased the amount of grease required would increase in proportion.

The variables tested for correlation are listed in Appendix B under Y_{25-28}. Results of this analysis follow.

Cost of Oil and Grease for All Tractors and for Plows and Disks--No variable examined showed any promise of explaining an appreciable amount of the cost variance of oil and grease for tractors, plows, or disks (Tables 9 and 10). This is likely due to two factors.

Table 9. Simple Correlation Coefficients Relating to Cost of Oil and Grease per Hour of Operation for All Tractors.

Variable	Designation of Variable	Drawbar Horsepower X_1	Model Year X_4	Repairs in Year Y X_6	Service Time per Hour X_7	Price of Oil X_9	Price of Grease X_{10}
			All Wheel (60 Observations)				
Cost of oil and grease	Y_{25}	.05	.04	.14	.05	-.12	.43
Drawbar horsepower	X_1		.33	.58	.18	-.09	-.05
Model year	X_4			.01	.06	.08	-.03
Repairs in year Y	X_6				.22	-.19	.22
Service time per hour	X_7					.12	.00
Price of oil (per qt.)	X_9						-.01
Price of grease (per lb.)	X_{10}						
			All Crawlers (76 Observations)				
Cost of oil and grease	Y_{26}	.04	.08	.12	.29	.10	.36
Drawbar horsepower	X_1		.22	.29	.16	-.10	-.02
Model year	X_4			-.08	-.10	.04	.07
Repairs in year Y	X_6				.21	-.14	-.08
Service time per hour	X_7					-.02	-.02
Price of oil (per qt.)	X_9						-.03
Price of grease (per lb.)	X_{10}						

Table 10. Simple Correlation Coefficients Relating to Cost of Grease per Hour of Operation for Plows and Disks.

Variable	Designation of Variable	Price of Grease X_{10}	Model Year of Implement X_{18}	Repairs in Year Y X_{20}	Service Time per Hour X_{21}	Number of Bottoms or Disks [1] X_{25}
			Plows (99 Observations)			
Cost of grease	Y_{27}	.12	.07	-.09	-.19	-.15
Price of grease (per lb.)	X_{10}		.09	.09	-.02	-.04
Model year of implement	X_{18}			.08	.27	-.04
Repairs in year Y	X_{20}				.09	.37
Service time per hour	X_{21}					.18
Number of bottoms or disks	X_{25}					
			Disks (109 Observations)			Total Width of Disk X_{23}
Cost of grease	Y_{28}	.12	.05	-.03	-.15	-.08
Price of grease (per lb.)	X_{10}		.17	.12	-.02	-.13
Model Year of implement	X_{18}			.09	.06	.25
Repairs in year Y	X_{20}				.08	.31
Service time per hour	X_{21}					.31
Total width of disk	X_{23}					

[1] Number of plow bottoms for moldboard plows or number of disk blades for disk plows.

First, respondents had no absolute measure of the actual amount of oil or grease used for each servicing. Secondly, while the relative cost variance was large, the absolute size of oil and grease cost per hour was very small (one to nine cents). Thus, the rather crude indexes used as explanatory variables were not sufficient.

Cost of Repairs for Tractors and Implements

Repair costs contribute to a substantial portion of the total per hour operational costs. Most repair costs are a result of use; however, some result from age alone. An example would be repairs to batteries. Batteries are often replaced once a year even if the tractor had limited use. If such repairs are relatively constant over the tractor lifetime, they would be uncorrelated with age. Other repairs are associated with use. For example, tire cost (although a tire will deteriorate with age) and motor repairs would be positively correlated with use.

Repair costs are a function of drawbar horsepower. As horsepower is increased, repairs will also increase because of the larger, more complex component parts of higher horsepower tractors.

The amount of service time employed per hour of operation could influence repair costs. When service time is adequate, repairs would be at a minimum because wear has been curtailed within practical limits. Inadequate service time would contribute to increased wear

which in turn would increase repair costs. Above a certain level, extra service time would probably be superfluous and not correlated with repair.

Different types and textures of soil possess different abrasive qualities. The degree of abrasiveness is associated with machine wear. Sandy and gravelly soils have high abrasive effects; thus, wear would be greater in these soils than in a loam or clay type soil. Increased wear contributes directly to increased repairs.

Irresponsible and careless operation of equipment increases repair costs. Examples would be operating at too high a speed or turning around field ends with plow in ground. There is no absolute measure of skill, so it was not possible to determine the correlation between skill and repairs.

Number and size of plow bottoms or disks and total width of disks are hypothesized as additional influencing variables on repair costs of these implements. In the case of plows, a certain amount of repairs is associated with each bottom or disk. Thus, as additional bottoms or disks are added, repair costs would increase. The same is true for disks. As additional width is added, an increase in repairs is expected because of the associated repairs with each width component. For example, it would be expected that the repair cost of a 14-foot disk would be twice that of a 7-foot disk of comparable make and model.

The variables tested as affecting the variance of repair costs are (1) drawbar horsepower, (2) age of tractor, (3) total accumulated hours, and (4) service time per hour of operation.

Data were too limited to include type and texture of soil in the formulation, nor was there adequate means available to quantify operator skill or dependability. The results of this analyses are shown below.

Repairs for Tractors--No promising variables appeared (Table 11). There was, however, a high positive correlation between age of tractor and total hours use. This shows that there was a similarity in the number of hours of use per year for tractors of similar ages.

Repairs for Moldboard Plows--The results show no relevant variables were discovered. Most values were low and of mixed sign (Table 12).

Repairs for Disk Plows--For disk plowing in sandy soil, age of plow and number of disks appear to be relevant variables. Age explains 46 per cent of the variance in repairs, whereas number of disks explains 35 per cent of the repair variance (Table 13). There is, however, a high correlation between age and number of disks. This was a very small sample. Evidently, by chance the older disk plows were all the largest. In all classifications, age is highly correlated with total use. Thus, while repair costs appear related to age alone they may be

Table 11. Simple Correlation Coefficients Relating to Cost of Repairs per Hour of Operation for All Tractors.

Variable	Designation of Variable	Drawbar Horsepower X_1	Age of Tractor X_3	Total Hours Used X_5	Service Time per Hour X_7
		All Wheel (60 Observations)			
Cost of repairs	Y_{29}	.11	.22	-.15	.08
Drawbar horsepower	X_1		.34	.11	.18
Age of tractor	X_3			.46	-.05
Total hours used	X_5				.04
Service time per hour	X_7				
		All Crawlers (76 Observations)			
Cost of repairs	Y_{30}	.13	.22	-.02	.06
Drawbar horsepower	X_1		-.22	.23	.16
Age of tractor	X_3			.47	.10
Total hours used	X_5				.33
Service time per hour	X_7				
		All Tractors (136 Observations)			
Cost of repairs	Y_{31}	.30	.32	.09	.13
Drawbar horsepower	X_1		.02	.36	.25
Age of tractor	X_3			.54	.12
Total hours used	X_5				.29
Service time per hour	X_7				

Table 12. Simple Correlation Coefficients Relating to Cost of Repairs per Hour of Operation Plowing with Moldboard Plows in Different Soil Types.

Variable	Designation of Variable	Age of Plow X_{17}	Total Hours[1] X_{19}	Service Time per Hour X_{21}	No. of Bottoms X_{25}	Size of Bottoms X_{26}
		All Soil Types (69 Observations)				
Cost of repairs	Y_{32}	.11	-.08	.07	.24	.10
Age of plow	X_{17}		.50	-.16	.04	-.06
Total hours	X_{19}			-.02	.45	.16
Service time per hour	X_{21}				.14	.06
Number of bottoms	X_{25}					.33
Size of bottoms	X_{26}					
		Sandy Soil (24 Observations)				
Cost of repairs	Y_{33}	-.12	-.22	-.01	.07	-.26
Age of plow	X_{17}		.64	-.23	.11	.27
Total hours	X_{19}			-.32	.52	.53
Service time per hour	X_{21}				.00	.10
Number of bottoms	X_{25}					.44
Size of bottoms	X_{26}					
		Other than Sandy Soil (35 Observations)				
Cost of repairs	Y_{34}	.33	.06	.08	.35	.16
Age of plow	X_{17}		.30	-.25	.13	-.05
Total hours	X_{19}			.12	.51	.12
Service time per hour	X_{21}				.17	.06
Number of bottoms	X_{25}					.31
Size of bottoms	X_{26}					

[1] Total lifetime accumulated hours.

Table 13. Simple Correlation Coefficients Relating to Cost of Repairs per Hour of Operation Plowing with Disk Plows in Different Soil Types.

Variable	Designation of Variable	Age of Plow X_{17}	Total Hours[1] X_{19}	Service Time per Hour X_{21}	No. of Disks X_{25}	Size of Disks X_{26}
		All Soils (21 Observations)				
Cost of repairs	Y_{35}	.34	.19	-.27	.29	.01
Age of plow	X_{17}		.60	-.32	.17	-.17
Total hours	X_{19}			.02	.53	-.33
Service time per hour	X_{21}				.17	.03
Number of disks	X_{25}					-.54
Size of disks	X_{26}					
		Sandy Soil (10 Observations)				
Cost of repairs	Y_{36}	.68	.32	-.22	.59	-.31
Age of plow	X_{17}		.73	-.19	.80	-.50
Total hours	X_{19}			.05	.63	-.15
Service time per hour	X_{21}				-.10	.51
Number of disks	X_{25}					-.45
Size of disks	X_{26}					
		Other than Sandy Soil (8 Observations)				
Cost of repairs	Y_{37}	.13	-.12	-.25	.10	.50
Age of plow	X_{17}		.56	-.74	-.38	.50
Total hours	X_{19}			-.37	.23	.13
Service time per hour	X_{21}				.39	-.33
Number of disks	X_{25}					-.39
Size of disks	X_{26}					

[1] Total lifetime accumulated hours.

indirectly related to use. A significant negative value appears between number of disks and size of disk, which indicates that as size of disks is increased, number of disks decreases. In sandy soil, service time is negatively correlated with size of disks. This means that as size of disks are increased, service time decreases because as size increases the number of disks decreases. Thus, less service time is required. In all soils and in sandy soil, total hours is positively correlated with number of disks which indicates that as number of disks increases, total use will increase. This is probably due to the practice of larger plows being purchased for larger operations. Other high correlations appear in these results, but due to the mixture of value and sign, their discussion seems unwarranted.

Repairs for Disks--No notable variables appear in the disk repair analysis. All values are below .23 (Table 14).

Cost of Service Labor for Tractors and Implements

Theoretically, the cost of service labor used per hour of operation is affected by the following relationships.

Late model tractors and equipment require less servicing than do older models. The use of sealed bearings in the later models has greatly reduced, or in some cases eliminated, regular greasing. Thus, the later models require less service time.

Table 14. Simple Correlation Coefficients Relating to Cost of Repairs per Hour Disking in Different Soil Types.

Variable	Designation of Variable	Age of Disk X_{17}	Total Hours X_{19}	[1] Service Time per Hour X_{21}	Total Width of Disk X_{23}
		All Soils (95 Observations)			
Cost of Repairs	Y_{38}	.05	-.09	-.16	.06
Age of disk	X_{17}		.25	-.06	.24
Total hours	X_{19}			.20	.25
Service time per hour	X_{21}				.28
Total width of disk	X_{23}				
		Sandy Soil (36 Observations)			
Cost of repairs	Y_{39}	.07	-.06	-.23	-.04
Age of disk	X_{17}		.41	-.06	-.44
Total hours	X_{19}			.11	.23
Service time per hour	X_{21}				.20
Total width of disk	X_{23}				
		Other than Sandy Soil (46 Observations)			
Cost of repairs	Y_{40}	.07	-.09	-.11	-.01
Age of disk	X_{17}		.35	-.14	-.21
Total hours	X_{19}			.07	.22
Service time per hour	X_{21}				.30
Total width of disk	X_{23}				

[1] Total lifetime accumulated hours.

The amount of time spent in servicing directly influences the service cost. It costs twice as much for labor for a ten-minute service time than it does for a five-minute one. So, as service time increases the cost incurred also increases.

The price paid service labor per hour influences the total hourly service cost. If ten minutes were used for servicing, the cost for labor at $1.25 per hour would be 25 per cent more than if $1.00 per hour was paid for labor. Thus, an increase in the hourly rate will increase service cost given the same efficiency level of labor.

Small, inadequate or inefficient servicing equipment induces higher service cost. When small grease guns are used, extra time is required to fill the gun before lubrication has been completed. Any time consumed that is not used in the actual service operation increases the service cost.

When individual containers, such as quarts of oil are used, additional time is consumed over using bulk facilities. If such a practice is followed, then service costs will necessarily increase over that of bulk handling.

In summary, the variables hypothesized as being most influential in the cost of service labor are (1) model year of machine, (2) service time expended per hour of operation, (3) the price paid service labor, (4) the adequacy of efficient servicing equipment, and (5) whether bulk or separate container materials are used.

Data were not available on the adequacy of servicing equipment or container types. Correlations between service cost and the hypothesized independent variables are presented below.

Service Labor for Tractors--In all classifications the amount of service time appears to be the one variable which explains an appreciable amount of the service labor cost variance (Table 15). Sixty-one per cent, 79 per cent, and 72 per cent of the variance is explained for all wheel, all crawler, and all tractors, respectively. Little correlation exists between amount of service time and price paid service labor. Price showed only a small influence on cost. Since price and time were not negatively correlated, this lack of correlation evidently was not due to increased efficiency. Apparently, the variance observed in the price of service labor was too small to have any effect. That is, the price of service labor was relatively constant; therefore, it naturally was not correlated with anything.

Model year had a low correlation with the cost of service labor which indicates that little influence is exerted by model year, or that the amount of service time is so insignificant that any reduction is of little effect.

Service Labor for Plows and Disks--The only variable promising to explain the variance of service labor cost for plows was amount of service time (Table 16). Twenty-five per cent of the variance was

Table 15. Simple Correlation Coefficients Relating to Cost of Service Labor per Hour of Operation for All Tractors.

Variable	Designation of Variable	Model Year of Tractor X_4	Service Time per Hour X_7	Price of Service Labor[1] X_8
	All Wheel (64 Observations)			
Cost of service labor	Y_{41}	-.02	.78	.25
Model year of tractor	X_4		.05	-.03
Service time per hour	X_7			-.10
Price of service labor	X_8			
	All Crawlers (84 Observations)			
Cost of service labor	Y_{42}	-.04	.89	.49
Model year of tractor	X_4		-.14	.09
Service time per hour	X_7			.11
Price of service labor	X_8			
	All Tractors (148 Observations)			
Cost of service labor	Y_{43}	.10	.85	.36
Model year of tractor	X_4		-.14	.09
Service time per hour	X_7			.01
Price of service labor	X_8			

[1] Price paid service labor per hour.

Table 16. Simple Correlation Coefficients Relating to Cost of Service Labor per Hour of Operation for Plows and Disks.

Variable	Designation of Variable	Price Paid Service Labor[1] X_8	Model Year of Implement X_{18}	Service Time per Hour X_{21}
	All Plows (107 Observations)			
Cost of service labor	Y_{44}	.28	.12	.50
Price paid service labor	X_8		.06	-.21
Model year of implement	X_{18}			.28
Service time per hour	X_{21}			
	All Disks (103 Observations)			
Cost of service labor	Y_{45}	.11	.13	.30
Price paid service labor	X_8		.01	-.20
Model year of implement	X_{18}			.06
Service time per hour	X_{21}			

[1] Price paid service labor per hour.

associated with amount of service time for plows. No variable showed promise in explaining the service time cost variance for disks.

Estimates Relating to Fixed Costs

Fixed costs are usually defined as including depreciation, interest on investment, taxes, insurance and housing. Housing cost is very small in Arizona. Because of favorable climate, most machinery is stored outdoors. Taxes and insurance costs may be computed from data supplied by the taxing or insuring agency. Housing, taxes, and insurance costs, unlike the costs considered by this study, are not random variables. Depreciation and interest on investment, however, may be computed from the variable, market value. If market value is influenced by factors other than time, a portion of depreciation and interest on investment is actually a variable cost. Explanation of these computations and an analysis of this variable are given below.

Market Value

Depreciation schedules commonly used for tax purposes may or may not approximate actual depreciation. Actual total depreciation is the difference between original cost and actual present market value. Depreciation for one particular year is obtained by subtracting present market value from the market value of the previous year. Interest on

investment in any one year is the actual market value times the applicable interest rate.

Present market value is more when original cost is higher. Assuming market value declines 25 per cent in one year, a machine costing $3,000 would have a higher market value than one costing $2,000 in the given year.

A certain amount of decline in market value is due to age alone--even if the machine had no use. This reflects both the influence of obsolescence brought about by technical innovations and deterioration due to time alone. An additional decline in market value is due to use alone. As use is increased market value is decreased.

Repairs in year Y are used as an index of machine condition. Market value is hypothesized as a function of condition, thus as condition deteriorates, market value will decline. If major repairs are made in a given year, market value would be expected to rise.--for example, the addition of $100 worth of new tires.

Service time is another variable used as a condition index. Machines that receive proper care and servicing are expected to have a higher market value than machines which do not receive such care. As service time is decreased, it would be expected that condition would be poorer which would contribute to a lower market value.

Certain interactions between variables may influence market value. One such interaction is the relationship between original cost

and age. The influence of ten years on the market value of a tractor is different for a $5,000 tractor than for a $3,000 one. One would expect the value of the more expensive piece of equipment to decline at a faster rate. An interaction between original cost and total hours of use is expected for a similar reason. The value of the more expensive equipment will decline at a faster rate than the cheaper equipment given the same number of hours use. One buys larger equipment to do larger jobs--not to obtain more total hours use.

The interaction of age and total hours is another variable which could explain some of the market value variance. Two tractors of the same age with differing intensity of use would not have the same market value.

Still another interaction, age on repairs, should contribute to the market value variance. It would not be expected that a major repair costing $200 would influence the market value of a machine one year old in the same magnitude that it would effect a machine ten years old. For a similar reason an interaction between total hours and repairs is expected.

Market value is also influenced by storage practices. When tractors are housed year-round, market value should be higher because of the machine's better general appearance.

Technological innovations influence market value by causing older models to become obsolete sooner than if the innovations had not been introduced.

No data on storage was available. In fact, little machinery storage per se is used in Arizona. Of course, painting and servicing may be substituted for storage facilities. No means to measure the effect of new innovations on market value is available. Therefore, the variables tested as influencing the variance in market value of tractors, plows, and disks are (1) the original cost, (2) age in year Y, (3) total hours used, (4) repairs in year Y, (5) service time per hour of use, (6) interaction of original cost and age in year Y, (7) interaction of original cost and total accumulated hours, (8) interaction of age in year Y and total accumulated hours, (9) interaction of age in year Y and repairs in year Y, and (10) interaction of total accumulated hours and repairs in year Y.

Market Value for Wheel Tractors--The most relevant variable is original cost. Ninety-two per cent of the variance in market value was associated with this variable (Table 17). Little information can be gained by using additional variables. In every case where a significant simple correlation for other variables appears the cross-correlation with original cost is high.

Table 17. Simple Correlation Coefficients Relating to Market Value for Wheel Tractors in Year Y (39 Observations).

Variable	Designation of Variable	Original Cost X_2	Age in Year Y X_3	Total Hours[1] X_5	Repairs in Year Y X_6	Service Time per Hour X_7	Product of $X_2 \times X_3$ X_{11}	Product of $X_2 \times X_5$ X_{12}	Product of $X_3 \times X_5$ X_{13}	Product of $X_3 \times X_6$ X_{14}	Product of $X_5 \times X_6$ X_{15}
Market Value	Y_{46}	.96	-.31	.25	.63	.18	.63	.75	-.02	.43	.73
Original Cost	X_2		-.27	.19	.69	.25	.71	.64	-.03	.50	.64
Age in Year Y	X_3			.38	-.10	-.19	.46	.04	.52	.35	.07
Total Hours[1]	X_5				.16	-.08	.44	.67	.92	.32	.77
Repairs in Year Y	X_6					.21	.54	.38	.02	.77	.49
Service Time per Hour	X_7						.10	-.01	-.14	.16	.07
Product of $X_2 \times X_3$	X_{11}							.59	.33	.68	.62
Product of $X_2 \times X_5$	X_{12}								.38	.36	.96
Product of $X_3 \times X_5$	X_{13}									.25	.50
Product of $X_3 \times X_6$	X_{14}										.50
Product of $X_5 \times X_6$	X_{15}										

[1] Total lifetime accumulated hours.

The variables, age and accumulated hours, did not appear as relevant variables contrary to expectations. Evidently, little variance in age and accumulated hours occurred within each classification of original cost.

Market Value for Crawler Tractors--Original cost is a relevant variable along with age. The original cost explains 52 per cent of the market value variance. Age explains 44 per cent of the market value variance (Table 18). The cross-correlation between cost and age is low enough to suggest that both variables influence market value variance appreciably. The other variables tested had low correlation coefficients. Apparently, age is much more influential in determining market value for crawlers than it is in estimating wheel tractor market value. However, these results were probably due to the chance that the age dispersion of crawler observations was much greater than it was for wheel tractors.

Market Value for All Tractors--All tractors were combined in the hope that the greater number of observations and the added variance in the independent variables would improve the correlations. No gain in information occurred (Table 19). It was concluded that the different tractor types should receive separate consideration.

Market Value for Moldboard Plows--Seventy-seven per cent of the market value variation for moldboard plows is explained by

Table 18. Simple Correlation Coefficients Relating to Market Value for Crawler Tractors in Year Y (42 Observations).

Variable	Designation of Variable	Original Cost X_2	Age in Year Y X_3	Total Hours[1] X_5	Repairs in Year Y X_6	Service Time per Hour X_7	Product of $X_2 \times X_3$ X_{11}	Product of $X_2 \times X_5$ X_{12}	Product of $X_3 \times X_5$ X_{13}	Product of $X_3 \times X_6$ X_{14}	Product of $X_5 \times X_6$ X_{15}
Market Value	Y_{47}	.72	-.66	-.21	.00	.05	-.28	-.04	-.29	-.10	-.07
Original Cost	X_2		-.50	.14	.12	-.05	.20	.41	.01	.06	.12
Age in Year Y	X_3			.30	.11	.08	.70	.18	.58	.37	.11
Total Hours[1]	X_5				.43	.09	.54	.93	.89	.45	.62
Repairs in Year Y	X_6					.22	.29	.41	.33	.90	.92
Service Time per Hour	X_7						.02	.07	.07	.21	.19
Product of $X_2 \times X_3$	X_{11}							.62	.70	.50	.30
Product of $X_2 \times X_5$	X_{12}								.80	.42	.58
Product of $X_3 \times X_5$	X_{13}									.49	.50
Product of $X_3 \times X_6$	X_{14}										.85
Product of $X_5 \times X_6$	X_{15}										

[1] Total lifetime accumulated hours.

Table 19. Simple Correlation Coefficients Relating to Market Value for All Tractors in Year Y (81 Observations).

Variable	Designation of Variable	Original Cost X_2	Age in Year Y X_3	Total Hours[1] X_5	Repairs in Year Y X_6	Service Time per Hour X_7	Product of $X_2 \times X_3$ X_{11}	Product of $X_2 \times X_5$ X_{12}	Product of $X_3 \times X_5$ X_{13}	Product of $X_3 \times X_6$ X_{14}	Product of $X_5 \times X_6$ X_{15}
Market Value	Y_{48}	.87	-.23	.21	.27	.21	.33	.40	.06	.19	.18
Original Cost	X_2		-.03	.42	.40	.22	.65	.65	.28	.36	.34
Age in Year Y	X_3			.42	.19	.03	.61	.27	.60	.37	.19
Total Hours[1]	X_5				.48	.12	.63	.88	.92	.49	.60
Repairs in Year Y	X_6					.26	.49	.52	.40	.91	.92
Service Time per Hour	X_7						.19	.16	.09	.24	.21
Product of $X_2 \times X_3$	X_{11}							.74	.68	.62	.45
Product of $X_2 \times X_5$	X_{12}								.75	.53	.63
Product of $X_3 \times X_5$	X_{13}									.52	.51
Product of $X_3 \times X_6$	X_{14}										.87
Product of $X_5 \times X_6$	X_{15}										

[1] Total lifetime accumulated hours.

original cost. The cost on age and cost on total hours interactions also appear promising (Table 20). However, the high cross-correlation between both of these variables and original cost indicates that the additional explanation achieved by their inclusion would be small.

Market Value for Disk Plows--The variables original cost, age in year Y, and service time appear to be relevant variables. They explain 81 per cent, 35 per cent, and 26 per cent of the market value variance, respectively (Table 21). The cross-correlation between these variables is relatively low so an appreciable amount of information should be gained by the inclusion of all three variables. The other variables tested had low coefficient values which suggests little gain in information would be realized by their inclusion.

Market Value for All Plows--The separate plow classifications were combined to see if more information could be gained from the aggregate observations (Table 22). Although the number of observations was greatly increased no additional information was gained. It appeared that the market value variance is best handled by the separate classifications.

Market Value for Tandem Disks--Original cost is the most relevant variable effecting the market value variance. The interaction of original cost on age appears to be influential, but the cross-correlation

Table 20. Simple Correlation Coefficients Relating to Market Value for Moldboard Plows in Year Y (46 Observations).

Variable	Designation of Variable	Original Cost X_{16}	Age in Year Y X_{17}	Total Hours[1] X_{19}	Repairs in Year Y X_{20}	Service Time per Hour X_{21}	Product of $X_{16} \times X_{17}$ X_{27}	Product of $X_{16} \times X_{19}$ X_{28}	Product of $X_{17} \times X_{19}$ X_{29}	Product of $X_{17} \times X_{20}$ X_{30}	Product of $X_{19} \times X_{20}$ X_{31}
Market Value	Y_{49}	.88	-.01	.45	.48	.15	.76	.59	.39	.47	.40
Original Cost	X_{16}		.08	.55	.62	.11	.88	.68	.48	.55	.46
Age in Year Y	X_{17}			.22	.06	.00	.37	.16	.42	.25	.13
Total Hours[1]	X_{19}				.59	.06	.62	.93	.94	.70	.81
Repairs in Year Y	X_{20}					.10	.51	.67	.55	.87	.77
Service Time per Hour	X_{21}						.05	.06	.03	.07	.05
Product of $X_{16} \times X_{17}$	X_{27}							.71	.67	.65	.51
Product of $X_{16} \times X_{19}$	X_{28}								.89	.76	.88
Product of $X_{17} \times X_{19}$	X_{29}									.76	.84
Product of $X_{17} \times X_{20}$	X_{30}										.87
Product of $X_{19} \times X_{20}$	X_{31}										

[1] Total lifetime accumulated hours.

Table 21. Simple Correlation Coefficients Relating to Market Value for Disk Plows in Year Y (20 Observations).

Variable	Designation of Variable	Original Cost X_{16}	Age in Year Y X_{17}	Total Hours[1] X_{19}	Repairs in Year Y X_{20}	Service Time per Hour X_{21}	Product of $X_{16} \times X_{17}$ X_{27}	Product of $X_{16} \times X_{19}$ X_{28}	Product of $X_{17} \times X_{19}$ X_{29}	Product of $X_{17} \times X_{20}$ X_{30}	Product of $X_{19} \times X_{20}$ X_{31}
Market Value	Y_{50}	.90	-.59	-.12	.12	.51	.16	.27	-.33	-.14	.11
Original Cost	X_{16}		-.46	.15	.43	.33	.52	.58	-.19	.22	.45
Age in Year Y	X_{17}			.50	-.04	-.39	.28	-.05	.78	.41	.00
Total Hours[1]	X_{19}				.34	-.45	.64	.77	.82	.51	.57
Repairs in Year Y	X_{20}					-.04	.50	.56	.04	.86	.93
Service Time per Hour	X_{21}						-.34	-.26	-.44	-.23	-.15
Product of $X_{16} \times X_{17}$	X_{27}							.76	.36	.70	.59
Product of $X_{16} \times X_{19}$	X_{28}								.30	.51	.75
Product of $X_{17} \times X_{19}$	X_{29}									.34	.19
Product of $X_{17} \times X_{20}$	X_{30}										.82
Product of $X_{19} \times X_{20}$	X_{31}										

[1] Total lifetime accumulated hours.

Table 22. Simple Correlation Coefficients Relating to Market Value for All Plows in Year Y (67 Observations).

Variable	Designation of Variable	Original Cost X_{16}	Age in Year Y X_{17}	Total[1/] Hours X_{19}	Repairs in Year Y X_{20}	Service Time per Hour X_{21}	Product of $X_{16} \times X_{17}$ X_{27}	Product of $X_{16} \times X_{19}$ X_{28}	Product of $X_{17} \times X_{19}$ X_{29}	Product of $X_{17} \times X_{20}$ X_{30}	Product of $X_{19} \times X_{20}$ X_{31}
Market Value	Y_{51}	.87	-.31	.21	.31	.27	.47	.41	.05	.22	.26
Original Cost	X_{16}		-.17	.43	.55	.17	.75	.62	.24	.44	.42
Age in Year Y	X_{17}			.27	.01	-.14	.30	.08	.56	.28	.08
Total Hours[1/]	X_{19}				.50	-.04	.63	.91	.88	.66	.78
Repairs in Year Y	X_{20}					.05	.49	.60	.35	.85	.74
Service Time per Hour	X_{21}						-.03	.01	-.11	.00	.02
Product of $X_{16} \times X_{17}$	X_{27}							.72	.58	.65	.52
Product of $X_{16} \times X_{19}$	X_{28}								.73	.71	.87
Product of $X_{17} \times X_{19}$	X_{29}									.64	.67
Product of $X_{17} \times X_{20}$	X_{30}										.84
Product of $X_{19} \times X_{20}$	X_{31}										

[1/] Total lifetime accumulated hours.

between these two variables is high (Table 23). Thus, no appreciable gain in information would result from including both variables.[1]

Market Value for Offset Disks--Sixty-six per cent of the market variance for offset disks is explained by original cost. No other variable tested shows promise of adding appreciably to the variance explanation (Table 24).

Market Value for All Disks--Again, all classifications were grouped together to see if additional information could be gained from the increased observations (Table 25). The results indicate, however, that no gain was achieved.

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[1] Three cross-correlation coefficients in Table 23 have a value of 1.00 which shows that these variables were perfectly correlated. For purposes of explaining variance in the dependent variable, these intercorrelation variables are identical.

Table 23. Simple Correlation Coefficients Relating to Market Value for Tandem Disks in Year Y (70 Observations).

Variable	Designation of Variable	Original Cost X_{16}	Age in Year Y X_{17}	Total[1/] Hours X_{19}	Repairs in Year Y X_{20}	Service Time per Hour X_{21}	Product of $X_{16} \times X_{17}$ X_{27}	Product of $X_{16} \times X_{19}$ X_{28}	Product of $X_{17} \times X_{19}$ X_{29}	Product of $X_{17} \times X_{20}$ X_{30}	Product of $X_{19} \times X_{20}$ X_{31}
Market Value	Y_{52}	.93	-.36	-.02	.07	-.09	.61	.32	-.17	.07	.07
Original Cost	X_{16}		-.18	-.11	-.09	.02	.79	.24	-.19	-.10	-.10
Age in Year Y	X_{17}			.47	.11	-.39	.46	.32	.73	.11	.11
Total Hours[1/]	X_{19}				.92	-.11	.22	.93	.93	.92	.92
Repairs in Year Y	X_{20}					.10	.03	.90	.71	1.00	1.00
Service Time per Hour	X_{21}						-.17	-.03	-.30	.10	.09
Product of $X_{16} \times X_{17}$	X_{27}							.45	.29	.02	.02
Product of $X_{16} \times X_{19}$	X_{28}								.80	.90	.90
Product of $X_{17} \times X_{19}$	X_{29}									.71	.72
Product of $X_{17} \times X_{20}$	X_{30}										1.00
Product of $X_{19} \times X_{20}$	X_{31}										

[1/] Total lifetime accumulated hours.

Table 24. Simple Correlation Coefficients Relating to Market Value for Offset Disks in Year Y (38 Observations).

Variable	Designation of Variable	Original Cost X_{16}	Age in Year Y X_{17}	Total Hours[1] X_{19}	Repairs in Year Y X_{20}	Service Time per Hour X_{21}	Product of $X_{16} \times X_{17}$ X_{27}	Product of $X_{16} \times X_{19}$ X_{28}	Product of $X_{17} \times X_{19}$ X_{29}	Product of $X_{17} \times X_{20}$ X_{30}	Product of $X_{19} \times X_{20}$ X_{31}
Market Value	Y_{53}	.81	-.41	.03	.19	.31	.15	.23	-.13	.13	.19
Original Cost	X_{16}		-.16	.22	.25	.33	.54	.46	-.14	.25	.20
Age in Year Y	X_{17}			.39	-.08	.12	.65	.23	.72	.14	-.09
Total Hours[1]	X_{19}				.70	.10	.45	.92	.84	.70	.74
Repairs in Year Y	X_{20}					.00	.11	.79	.30	.92	.94
Service Time per Hour	X_{21}						.25	.13	.08	-.05	.03
Product of $X_{16} \times X_{17}$	X_{27}							.55	.68	.30	.06
Product of $X_{16} \times X_{19}$	X_{28}								.71	.75	.81
Product of $X_{17} \times X_{19}$	X_{29}									.45	.32
Product of $X_{17} \times X_{20}$	X_{30}										.79
Product of $X_{19} \times X_{20}$	X_{31}										

[1] Total lifetime accumulated hours.

Table 25. Simple Correlation Coefficients Relating to Market Value for All Disks in Year Y (68 Observations).

Variable	Designation of Variable	Original Cost X_{16}	Age in Year Y X_{17}	Total Hours[1] X_{19}	Repairs in Year Y X_{20}	Service Time per Hour X_{21}	Product of $X_{16} \times X_{17}$ X_{27}	Product of $X_{16} \times X_{19}$ X_{28}	Product of $X_{17} \times X_{19}$ X_{29}	Product of $X_{17} \times X_{20}$ X_{30}	Product of $X_{19} \times X_{20}$ X_{31}
Market Value	Y_{54}	.84	-.36	.09	.18	.28	.29	.28	-.08	.14	.19
Original Cost	X_{16}		-.26	.18	.18	.29	.57	.40	.04	.12	.16
Age in Year Y	X_{17}			.25	-.02	-.04	.47	.07	.64	.21	-.03
Total Hours[1]	X_{19}				.71	.13	.42	.93	.85	.71	.74
Repairs in Year Y	X_{20}					.04	.17	.73	.44	.90	.92
Service Time per Hour	X_{21}						.16	.19	.07	.00	.06
Product of $X_{16} \times X_{17}$	X_{27}							.50	.59	.33	.13
Product of $X_{16} \times X_{19}$	X_{28}								.70	.67	.77
Product of $X_{17} \times X_{19}$	X_{29}									.62	.44
Product of $X_{17} \times X_{20}$	X_{30}										.76
Product of $X_{19} \times X_{20}$	X_{31}										

[1] Total lifetime accumulated hours.

CHAPTER III

SUGGESTED IMPROVEMENTS IN METHODOLOGY

The data tested in this study did not produce enough highly correlated variables to warrant a multiple regression analysis using these data. However, there is reason to believe that multiple regression equations can be developed by further work. With improved schedules, better data procurement, and by using the experience gained in this study more reliable cost estimates should result. If this is not the case, the whole area of machinery cost estimation is left in doubt. Machinery costs do vary; this variance must be subject to explanation. In any case, where the variance is subject to a logical explanation, multiple regression can give better results than simple averages.

As costs of machinery ownership and operation increase, the need for more reliable cost estimates is intensified. Thus, further work in this area would be justified.

The Sample

The experience gained in this study implies that the method of selecting the sample should be changed. A simple random sample

(proportionate or not) usually results in most observations occurring rather close to the mean value of the sample. Very few, if any, observations are obtained at either extreme. Thus, the sample does not show all possible combinations of variables. A purposive sample would prove more satisfactory. This type of sampling obtains information pertaining to all possible combinations--the sample contains the extreme cases as well as the commonly found cases. For example, in the present study, the ages of most gasoline wheel tractors were clustered around two to three years. The variance in age was not great enough to show up as a contributing factor to market value. Purposive sampling would search out tractors of all relevant ages. Then, if age were a contributing factor, it would have a chance to show its effect.

Since each and every two-variable combination should show a large range of values, much more time would be involved in obtaining a complete purposive sample than was involved in the present random sample.

The Data

All data were obtained from memory in the present study. For some variables this procedure surely is adequate. Data on tractor horsepower, original cost, age, and size of equipment are examples of information which can satisfactorily be obtained in this manner.

These data are facts; an estimate by the owner is not necessary. Also, integer accuracy should be satisfactory. In other cases, however, the farmers' memories and informal estimates may not be satisfactory.

Market Value

It was believed that the owner would have a good estimate of present value. Presumably he is abreast of the market, knows the condition of his equipment, etc. Without testing this hypothesis, however, one cannot be sure that owner estimates and market values would coincide. Actual market value is the really relevant variable. The question is--do market values vary due to use, condition, state of repair, etc., or do they merely reflect original cost and age? These latter two variables are reflected in bluebook values. Owner estimates seemed to merely follow the bluebook. If these other variables are not relevant, it would be irrational for an owner to keep his equipment in an extremely high state of condition. Data on actual equipment sales, coupled with repair, use, age, and condition data, would be extremely difficult to obtain in quantity. Yet, these data are necessary if progress is to be made on estimation of ownership costs.

Repairs

In order to make a reliable estimate on repair costs per hour, total accumulated hours of use and total accumulated repairs must be

known. This would involve access to good records. Repairs in any one particular year are a function of previous use and previous repairs. The need for repairs occurs due to the accumulated effect of use. To illustrate, a major motor overhaul is the result of accumulated wear over time. Any amount of use contributes to this accumulation so the cost of repairs, although made in a specific year, is attributable to the total use period between such overhauls. While one would expect the average repair cost per year for a machine to increase over time, repairs in any one year might range from a large amount to nothing. Therefore, data on one year's repair proved inadequate. Also, the assumption that total accumulated hours was equal to the hours use in the observed year times the machine's age may have been incorrect in some instances.

Fuel Consumption

More concise tabulation of fuel consumption is needed. Generally, consumption was reported in whole or half gallon increments. This rounding procedure tends to mask that part of the variance which can be attributed to the effect of a specific variable. For example, if the installation of new spark plugs reduced fuel consumption by .2 gallons per hour, this effect would not be shown in an analysis using whole or half gallon data. Information of this precision could not be obtained in any appreciable quantity from owners. Probably this type of data would

have to be acquired by actually testing the effects of different repairs on fuel consumption under experimental conditions. Also, important would be the rate of increase in fuel consumption between repair periods.

Service Time

A more equitable means than owner estimation of determining the actual service time devoted to a particular machine is needed. This suggests a time and motion study. It is recognized that the cost of service time is one of the lesser cost components of machinery operation; still, large variation in time used was reported. If the reason for variation in several small cost components is ignored, the aggregate variation could prove quite large.

Oil and Grease Use

There seemed to be a tendency for owners to minimize the amount of oil and grease reported as used. Some reported as little as one-fourth pound of grease used per servicing. Others indicated that the oil used between changes was negligible. This may be true, but if a dependable aggregate estimate is to be developed, then all factors must be considered. Several supposedly negligible items might possibly contribute to sizeable effects. Time and motion studies (including the measurement of materials used) seem to be the only answer.

Field Capacity

Estimates of field capacities were also usually obtained in round figures. While these data were supposedly with a particular soil texture, and depth of tillage for one specific field, it is suspected that some "average" field capacity was obtained. Again, actual measurement of the data appears necessary for satisfactory regression analysis.

Alternatives in Securing Data

One alternative in obtaining data for machine cost regression analysis is to enlarge the sample to include several states. It would be hoped that by obtaining many more observations over a wider geographic area that all possible combinations of variable values might be obtained. The need for a strictly purposive sample would be eliminated simply by the quantity of data. Of course, inaccuracies in data measurement would remain. Hopefully, these data inaccuracies would cancel out. While the resulting cost estimates might still exhibit a large variance, most of the causative variables could be identified.[1]

Another alternative is to set up experimental tests. This method would be especially advantageous where accuracy in measurement is

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[1] This methodology is presently being attempted by a committee of agricultural economists from eight western states (Regional Project W-62).

necessary. It would be practically impossible to secure adequate data on the effect of repairs on fuel consumption from farmer cooperators. Records are not kept on this type of data, and it is doubtful that many owners would be willing to devote the time and equipment necessary in order to obtain these data.

This type of testing would also be advantageous in determining the effects of soil type on speed, repairs, and fuel consumption; in making accurate service time cost estimates; and in studying oil and grease costs. On the other hand, market value estimates must be obtained from nonexperimental data.

It is recognized that the cost of such experimentation would be high. Yet, some experimental tests of a similar nature are run, for example, The Nebraska Tractor Tests. The problem is to get these tests run in a form that is compatible with regression analysis.

CHAPTER IV

SUMMARY

The general objective of this study was to test the reliability of cost data collected by the farm survey method. Cost data of this type exhibits wide variance. If these data were reliable, this variance could be explained by correlation and/or regression analysis.

Initial analysis indicated that complete regression equations were impractical with available data. Therefore, correlation analysis was used as a preliminary analytical tool to determine the reliability of individual estimates and the relevance of individual variables. Suggestions for improvements in data necessary for complete regression analysis were then made.

The data analyzed were obtained from a proportionate random sample of 146 farmers who had cotton allotments in four Arizona counties. Data were restricted to those on tractors, plows, and disks.

Independent variables (listed in Appendix B) were hypothesized for each of the following dependent variables for several classes of tractors, plows, and disks. The dependent variables were field capacity,

fuel consumption, cost of oil and grease, cost of repairs, cost of service labor, and market value.

In each case, the hypothesized independent variables were each correlated with the dependent variable. If the correlation was .50 or higher, the independent variable was considered relevant. That is, an appreciable amount of the variance in the dependent variable was explained. In addition, the observations of both the dependent and independent variables were considered relatively reliable.

Correlated Variables

The following notable correlations were found. Drawbar horsepower was correlated with field capacity when plowing and disking with wheel tractors. Drawbar horsepower, repairs in year Y, and acres per hour were correlated with fuel consumption for gasoline wheel tractors. Fuel consumption for diesel wheel tractors both plowing and disking was correlated with service time. Drawbar horsepower was correlated with fuel consumption for crawler tractors when plowing and disking. The amount of service time was correlated with cost of service time for tractors and implements. The original cost of tractors and implements was highly correlated with present market value. Age and amount of service time were also correlated with present market value for disk plows.

Uncorrelated Variables

Several independent variables showed promise of being highly correlated with dependent variables had additional data been available. The most promising of these follow. Soil type, width of equipment, and depth of tillage showed a marginal correlation with field capacity. Age and amount of service time were marginally correlated with present market value.

No correlations were found for crawler tractor field capacity, cost of oil and grease for all tractors and implements, nor cost of repairs for all tractors and implements. The surplus power of crawler tractors seemed to mask the effects of the other independent variables when estimating field capacity. Insufficient data and the lack of precise measures of quantities used apparently were responsible for the lack of correlation when estimating the cost of oil and grease for tractors and implements. The cost of repair results were inconclusive. Repair observations were obtained for only one year. Observations on accumulated repair costs should prove more satisfactory. Age failed to show correlation with cost of service time. Apparently, too few newer tractors and implements which require little or no service time were contained in the sample.

Suggested Alternatives in Data Procurement

The alternatives suggested for securing the needed additional data were (1) using a purposive rather than a random sample, (2) expanding the sample size to include several states so that a greater variance could be observed, and (3) obtaining the data from experimental results. The data for such dependent variables as field capacity, fuel consumption, and cost of oil and grease must be obtained by experimental means to be reliable.

Conclusion

This report has shown the results of a preliminary attempt to use regression methods to estimate farm machinery costs and explain farm machinery cost variance. Previous work in machinery cost has failed to cope empirically with the reasons for cost variation. The limited results of this preliminary effort are evident to the author. Nevertheless, it is hoped that this effort may lead the way for further work, using a more precise methodology leading to accurate farm machinery cost estimation.

BIBLIOGRAPHY

American Society of Agricultural Engineers, Agricultural Engineers Yearbook, St. Joseph, 1959.

Department of Agricultural Engineering, Nebraska Tractor Test Reports, University of Nebraska, Lincoln, 1940 through 1961.

Ezekiel, Mordecai, Methods of Correlation Analysis, John Wiley and Sons, Inc., New York, 1953.

"Implement and Tractor," Red Tractor Book, Kansas City 5, Missouri, 1958.

Pearson, Frank A. and Kenneth B. Bennett, Statistical Methods, John Wiley and Sons, Inc., New York, 1951.

Spurr, William A., Lester S. Kellogg, and John H. Smith, Business and Economic Statistics, Richard D. Irwin, Inc., Homewood, Illinois, 1955.

APPENDICES

APPENDIX A

Definition of Dependent Variables

Definition of Independent Variables for Tractors

Definition of Independent Variables for Plows and Disks

APPENDIX B

Relationships Subjected to Empirical Analysis

APPENDIX C

Copy of Tractor Schedule

Copy of Tillage Machine Schedule

APPENDIX A

Definition of Dependent Variables

$Y_{1\text{-}16}$ = Field capacity per hour for given tractor and implement.

$Y_{17\text{-}24}$ = Fuel consumption per hour for all tractors.

$Y_{25\text{-}26}$ = Cost of oil and grease per hour of tractor operation.

$Y_{27\text{-}28}$ = Cost of grease per hour of plow and disk operation.

$Y_{29\text{-}31}$ = Cost of repairs per hour for all tractors.

$Y_{32\text{-}34}$ = Cost of repairs per hour for moldboard plows.

$Y_{35\text{-}37}$ = Cost of repairs per hour for disk plows.

$Y_{38\text{-}40}$ = Cost of repairs per hour for all disks.

$Y_{41\text{-}43}$ = Cost of service labor per hour of tractor operation.

$Y_{44\text{-}45}$ = Cost of service labor per hour of plow or disk operation.

$Y_{46\text{-}48}$ = Market value for all tractors.

$Y_{49\text{-}51}$ = Market value for all plows.

$Y_{52\text{-}54}$ = Market value for all disks.

Definition of Independent Variables for Tractors

X_1 = Max. drawbar H.P. of tractor.

X_2 = Original cost of tractor. ($)

X_3 = Age of tractor in year Y.

X_4 = Model year of tractor.

X_5 = Total accumulated hours on tractor (hours in year Y times age assuming constant use per year).

X_6 = Repairs in year Y on tractor ($).

X_7 = Service time per hour of tractor operation (hundredths of hour).

X_8 = Price of service labor per hour (cents).

X_9 = Price of oil per quart (cents).

X_{10} = Price of grease per pound (cents).

$X_{11} = X_2 X_3$

$X_{12} = X_2 X_5$

$X_{13} = X_3 X_5$

$X_{14} = X_3 X_6$

$X_{15} = X_5 X_6$

Definition of Independent Variables for Plows and Disks

X_{16} = Original cost of implement ($).

X_{17} = Age of implement in year Y.

X_{18} = Model year of implement.

X_{19} = Total accumulated hours on implement (hours in year Y times age assuming constant use per year).

X_{20} = Repairs in year Y on implement ($).

X_{21} = Service time per hour of implement operation (hundredths of hour).

X_{22} = Depth of tillage (inches).

X_{23} = Total width of tillage equipment (inches).

X_{24} = Acres per hour (nearest tenth).

X_{25} = Number of plow bottoms or disks.

X_{26} = Size of plow bottoms or disks (inches).

$X_{27} = X_{16} X_{17}$

$X_{28} = X_{16} X_{19}$

$X_{29} = X_{17} X_{19}$

$X_{30} = X_{17} X_{20}$

$X_{31} = X_{19} X_{20}$

APPENDIX B

Relationships Subjected to Empirical Analysis

Field capacity per hour with given implement--$Y_{1\text{-}16} = f(X_1, X_{22}, X_{23})$

Y_1 = Wheel tractors, plowing in light soil.

Y_2 = Wheel tractors, plowing in medium soil.

Y_3 = Wheel tractors, plowing in heavy soil.

Y_4 = Wheel tractors, plowing in all soils.

Y_5 = Wheel tractors, disking in light soil.

Y_6 = Wheel tractors, disking in medium soil.

Y_7 = Wheel tractors, disking in heavy soil.

Y_8 = Wheel tractors, disking in all soils.

Y_9 = Crawler tractors, plowing in light soil.

Y_{10} = Crawler tractors, plowing in medium soil.

Y_{11} = Crawler tractors, plowing in heavy soil.

Y_{12} = Crawler tractors, plowing in all soils.

Y_{13} = Crawler tractors, disking in light soil.

Y_{14} = Crawler tractors, disking in medium soil.

Y_{15} = Crawler tractors, disking in heavy soil.

Y_{16} = Crawler tractors, disking in all soils.

Fuel consumption per hour--$Y_{17-24} = f(X_1, X_6, X_7, X_{22}, X_{23}, X_{24})$

Y_{17} = Wheel tractors, gasoline, plowing.

Y_{18} = Wheel tractors, gasoline, disking.

Y_{19} = Wheel tractors, diesel, plowing.

Y_{20} = Wheel tractors, diesel, disking.

Y_{21} = Crawler tractors, plowing.

Y_{22} = Crawler tractors, disking.

Y_{23} = Diesel tractors, plowing.

Y_{24} = Diesel tractors, disking.

Cost of oil and grease per hour of tractor operation--$Y_{25-26} = f(X_1, X_4, X_6, X_7, X_9, X_{10})$

Y_{25} = All wheel tractors.

Y_{26} = All crawler tractors.

Cost of grease per hour of plow and disk operation--For all plows $Y_{27} = f(X_{10}, X_{18}, X_{20}, X_{21}, X_{25})$.

For all disks $Y_{28} = f(X_{10}, X_{18}, X_{20}, X_{21}, X_{23})$

Cost of repairs per hour for tractors--$Y_{29-31} = f(X_1, X_3, X_5, X_7)$

Y_{29} = All wheel tractors.

Y_{30} = All crawler tractors.

Y_{31} = All tractors.

Cost of repairs per hour for moldboard plows--$Y_{32-34} = f(X_{17}, X_{19}, X_{21}, X_{25}, X_{26})$

Y_{32} = In all soils.

Y_{33} = In sandy soil.

Y_{34} = In other than sandy soil.

Cost of repairs per hour for disk plows--$Y_{35-37} = f(X_{17}, X_{19}, X_{21}, X_{25}, X_{26})$

Y_{35} = In all soils.

Y_{36} = In sandy soil.

Y_{37} = In other than sandy soil.

Cost of repairs per hour for disks--$Y_{38-40} = f(X_{17}, X_{19}, X_{21}, X_{23})$

Y_{38} = In all soils.

Y_{39} = In sandy soil.

Y_{40} = In other than sandy soil.

Cost of service labor per hour of tractor operation--$Y_{41-43} = f(X_4, X_7, X_8)$

Y_{41} = All wheel tractors.

Y_{42} = All crawler tractors.

Y_{43} = All tractors.

Cost of service labor per hour of plow or disk operation--$Y_{44-45} = f(X_8, X_{18}, X_{21})$

Y_{44} = All plows.

Y_{45} = All disks.

Market value for tractors--$Y_{46-48} = f(X_2, X_3, X_5, X_6, X_7, X_{11}, X_{12}, X_{13}, X_{14}, X_{15})$

Y_{46} = All wheel tractors.

Y_{47} = All crawler tractors.

Y_{48} = All tractors.

Market value for plows--$Y_{49-51} = f(X_{16}, X_{17}, X_{19}, X_{20}, X_{21}, X_{27}, X_{28}, X_{29}, X_{30}, X_{31})$

Y_{49} = Moldboard plows.

Y_{50} = Disk plows.

Y_{51} = All plows.

Market value for disks--$Y_{52-54} = f(X_{16}, X_{17}, X_{19}, X_{20}, X_{21}, X_{27}, X_{28}, X_{29}, X_{30}, X_{31})$

Y_{52} = Tandem disks.

Y_{53} = Offset disks.

Y_{54} = All disks.

APPENDIX C

Dept. of Agr. Economics
University of Arizona

Farm No._____

Tractor Schedule

Make_____Model_____Year_____Fuel_____Year Purchased_____

Original Cost $_____Present Value $_____Disposal Year _____

Type of Insurance_____Type of Housing_____

Jobs Performed	X	Acres	Machine Used	Hours IX	Remarks

Has there been or have you planned a major change in the hours of annual use of this tractor on your farm? Yes [ ] No [ ] If so describe _____

_____

_____

Tractor Schedule (continued)

Repairs	Date No. 1		Date No. 2		Date No. 3		Cost		Remarks
	Mo.	Year	Mo.	Year	Mo.	Year	Parts	Labor	
Rings									
Valves									
Points									
Plugs									
Rear tires									
Front tires									
Battery									

Tillage Machine Schedule

Tillage Machine Schedule for:_____Farm No. _____

Make_____Size_____Year_____Year Purchased_____

Original Cost $_____Present Value $_____Disposal Year_____

Type of Insurance_____Type of Housing_____

Crop	X	Acres	Tractor Used	Remarks

Has there been or have you planned a major change in the hours of annual use of this machine on your farm? Yes /___/ No /___/ If so describe_____

_____

_____

Select a Typical Field Tilled by this Machine

Crop_____Following_____Previous Preplant oper.(s)____

Soil Type_____Acres_____Length_____Width_____

Tractor_____Driver Wage $____/hr. $____/mo. for_____hrs.

Field time IX (Gross)_____hrs. Down time IX_____hrs.

Fuel IX_____gals. at. $_____Include Storage?_____Depth of Tillage_____

Tillage Machine Schedule (continued)

Servicing Schedule and Materials for this Type of Field Work

	Tractor grease	Oil change	Oil filter	Air cleaner	Add fuel	Gr.till. mach.
Operating hours between servicing						
Material used (amount)						
" " (cost)						
Time per service						

Repair Schedule for this Tillage Machine

Item	Date No. 1		Date No.2		Date No. 3		Cost		Remarks
	Mo.	Year	Mo.	Year	Mo.	Year	Parts	Labor	

Do you have a repair shop? Replacement cost for shop $_____

Replacement cost tools $_____

_____