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A Case Study of California Farm Machinery: Repair Costs and Downtime

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Introduction

Farm machinery acquisition, operating and repair costs are an important cost component for commercial farms. Recent financial pressures combined with changes in income tax law investment incentives have altered decision parameters for machinery investment, replacement, repair, and use. Financial pressures are related to reduced sales of new equipment, liquidations of used equipment and increased repair costs. Nationwide, purchases of new farm machinery increased from $4.5 billion in 1969 to a high of $14.3 billion in 1979 and then decreased to $7.7 billion in 1985 (U.S. Department of Agriculture, 1986). Farm machinery repair costs rose steadily from $1.8 billion in 1969 to $5.7 billion in 1979 and further to $6.5 billion in 1984 before declining slightly to $6.1 billion in 1985. Farm machinery repair costs represented 7.3 percent of total operating expenses of farm firms in 1985 while machinery represented 12 percent of total farm assets.

It is generally acknowledged that farm machinery deteriorates with age and use. Thus, one can expect repair costs to increase over the useful life of a piece of machinery. Breakdowns involve two types of costs: There are repair costs for parts and labor and there may be costs associated with forced idleness. Breakdowns can delay field operations for which timeliness is critical, such as planting, pest control, and harvesting. Producers often have a contractual delivery schedule with processors for crops, such as tomatoes and sugar beets, and that which is not delivered on the contracted date may not be sold. Quality deterioration due to harvest delay may result in decreased returns, or in extreme cases, product rejection. Farmers often protect against breakdowns during critical operations through performance of preventive maintenance and by maintaining excess machinery capacity.

Financial data necessary for machinery investment decisions, including new and used machinery prices, interest rates and income tax provisions, are readily available to the individual decision maker. There is, however, very limited information regarding the effects of cumulative use on farm machinery repair costs and downtime for use in these decisions. This report presents case study data on these relationships from two large California row crop operations for crawler tractors, wheel tractors, grain combines and tomato harvesters. Quantitative relationships for farm machinery repair costs as a function of age (as reflected by cumulative machine hours) and annual use together with downtime as a function of cumulative machine hours will be estimated from data provided by the two case study farms.

Previous Studies

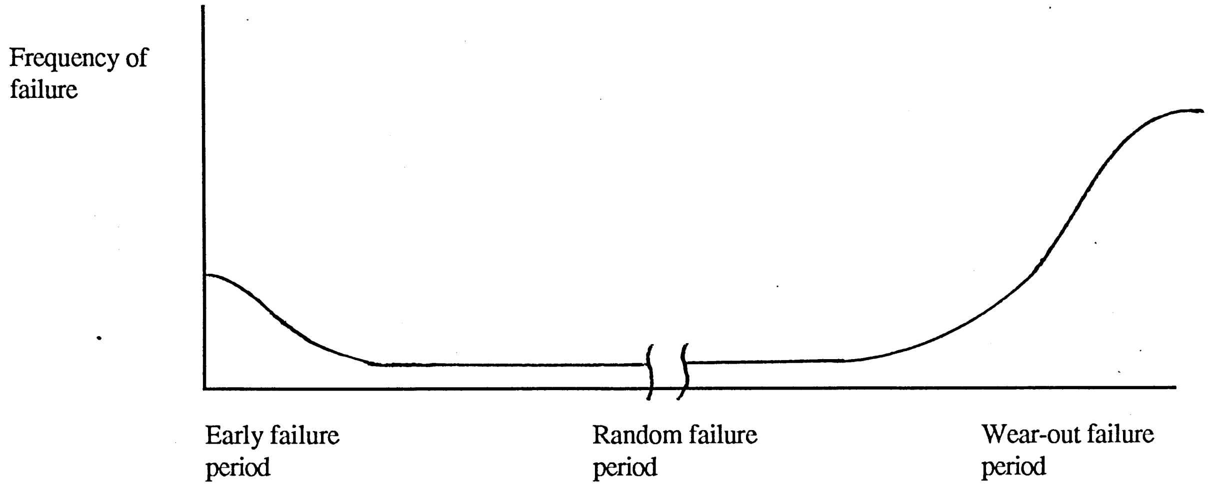
One approach to incorporating machinery repair costs in crop budgets is to include a flat charge per acre. Although this approach is easy to implement, it ignores the fact that farm machinery tends to deteriorate as it ages and that repair costs per hour of use may vary with the level of annual use. The small number of published farm machinery repair cost studies have generally found that repair costs increase with age as measured by cumulative machine hours. Using midwestern survey data, Larsen and Bowers (1965) and Bowers and Hunt (1970) examined average repair rates, defined as dollars per hour per $1,000 of initial machine price, as a function of the proportion of machine life used, defined as cumulative machine hours divided by expected life in hours. Average repair rates for some machines, such as combines, tended to increase at a constant rate throughout the useful life, while the average repair rates for others, such as tractors, increased at a decreasing rate over the useful life. A major limitation of these studies was that cumulative machine hours had to be estimated from the usage during the survey year. Given the absence of substantiating data, one might also question the useful lives specified for some of the machines, which ranged from a total of 1,000 hours for grain drills and mowers, to 2,000 hours for discs, plows and combines, to 12,000 hours for tractors.. The case study farms, for example, had observations on 14 combines with over 3,700 cumulative hours and, of these, six had over 4,500 hours. The 12,000 hour life for tractors, however, was in line with the case study observations.

Limited research has been done concerning farm machinery downtime. Machinery repair costs and downtime are clearly related but subject to substantial variability. Some repair costs are due to preventative maintenance, and the amount of downtime is not necessarily correlated with the magnitude of the repair cost. An expensive part may be replaced in minimal time and vice versa. Relatively new machinery under warranty may have downtime, but the producer will not be liable for repair costs.

Mechanical engineers have represented failure rates for machinery by a "bathtub curve" as shown in Figure 1 (Amstadter, 1973). Early failures are those which occur due to some flaw in the design, manufacturing or inspection process. The random failure period spans the major operating period of a machine. During the wear-out failure period, there is an increase in the failure rate due to parts degradation with age. An exponential distribution can be used to characterize the failure rate (increasing at a constant rate) during the random and wear-out failure periods. The relative probabilities for these periods may vary from the relationship depicted in Figure 1 because of complexity of the machine or manufacturing quality and quality control. The frequency of early failures can sometimes be reduced if the manufacturer performs extensive inspections before shipping its machinery or if the dealer carefully inspects the machinery before delivery to the customer.

Kumar, Goss and Studer (1977) examined combine harvester downtime rates using data from a California operation. They did not find any significant differences in the mean time between failures for different ages of machinery. However, the age distribution in their sample was relatively narrow; the maximum cumulative number of hours on a combine was 1,800 hours. Thus, most of the

Figure 1. Relative Failure Rates During a Machine's Life History.



Source: Amstadter, Reliability Mathematics, McGraw-Hill, 1973, p. 9.

machines could have still been in the random failure period.

Hunt (1971) conducted a reliability study of various kinds of midwestern farm equipment. He examined the incidence of machinery breakdowns using machine age (rather than cumulative hours) as the explanatory variable. He determined that reliability of machinery decreases and duration of downtime increases with machine age. Breakdown rates for self-propelled combines were noticeably higher than those for less complex machines.

The Data

Until recently, few farm operations maintained complete farm machinery repair cost and downtime records. While microcomputers have made it easier to record, process and maintain such information, it still is not readily available. We were fortunate to locate and gain access to detailed records for the four most common and costly types of farm machinery used on California row crop farms, including crawler tractors, wheel tractors, grain combines and tomato harvesters. All of the information pertaining to tractors and combines was obtained from a single large farm operation located in the San Joaquin Valley. The data for tomato harvesters were collected from another San Joaquin Valley operation. Both of these farms had large repair shops which maintained extensive records on the machinery which they serviced. In particular, cumulative machine hours together with labor and parts costs for each equipment item were recorded for each sevice incident and annual summaries of all costs were prepared for each piece of equipment.

Repair costs can be affected by many variables including, but not limited to, soil conditions, cropping patterns, operating practices, maintenance policies and repair practices. These variables have minimal impact on the data in this study since the data are all from two large farming operations. These data have the further advantage of being based on uniform reporting practices and complete repair records. One must exercise caution, however, when attempting to extend these results to other operations where the variables mentioned above may differ. Our results are for a case study, not a random sample, and the results cannot be generalized to all farm machinery of the types studied.

A variety of manufacturers and models were represented in the machinery fleets of the two farm firms. They operated two brands of crawler tractors, two brands of tomato harvesters, three brands of wheel tractors and three brands of combines. There were several distinct sizes of tractors; this analysis focuses on a medium crawler tractor with a rating of 216 horsepower and on two-wheel drive diesel wheel tractors with 100 to 130 PTO horsepower. The grain combines were 13 to 16 foot header models and the tomato harvesters were all electronic eye (color sorting) models.

Observations for the equipment items studied cover a wide range of annual use and cumulative hours. Data in Table 1 reflect the high annual usage of equipment on many California farms. The crawler tractor which logged 3,084 hours during one year, for example, was used an average of over 59 hours weekly for each week of the year. The case study farms' annual average use by equipment type were: crawler tractors, 1,745 hours; wheel tractors, 1,051 hours; combines, 565 hours; and tomato harvesters, 461 hours. The maximum observed cumulative hours by equipment type were: crawler tractors, 10,979 hours; wheel tractors, 10,976 hours; combines, 4,610 hours; and tomato harvesters, 5,318 hours (Table 1).

Both in-season repairs for breakdowns and pre-season preventative maintenance were performed on the machinery. Preventative maintenance costs can be substantial, especially when the costs of breakdowns are high. Farms which grow tomatoes, for example, perform extensive preventative maintenance on their tomato havesters during the off-season as a way of insuring against untimely breakdowns. There is very little slack in tomato harvesting schedules because of perishability and processor schedules. Processors will refuse to accept late loads when they are operating at capacity. Thus, the costs of delay associated with a tomato harvester breakdown can be very high.

The repair cost data collected for this study were for the period 1971 through 1982. The number of observations for each machine varied with the date of purchase and sale of the machine; some machines were operated over the entire 12-year period. Annual repair costs for each machine consist of labor and parts costs. Preventative maintenance performed during the off-season was included as a repair cost but oil and lube charges for periodic service were excluded. Labor charges were based on the costs to the firms of the mechanics doing the repairs. The cost of benefits was included. Unlike some smaller farm operations, there was no "free" operator labor associated with the repairs.

All repair costs were reported in

Table 1. Range of Observed Annual and Cumulative Hours of Use by Machine Type

Machine	Annual Use Average	Annual Use Range	Cumulative Use Range
Crawler tractors	1,745	610-3,084	610-10,979
Wheel tractors	1,051	72-1,881	72-10,976
Combines	565	424-631	493-4,610
Tomato harvesters	461	233-712	345-5,318

nominal terms. Repair costs were adjusted for inflation by use of a repair cost index based on data from the two case study farms. The index, based on 1981 dollars, was constructed from data on prices paid for some common repair parts and on the firms' average annual wage rates for mechanics (see Table 2). Note that the annual change in this index during the study period was very similar to the U.S. Department of Labor, Bureau of Labor Statistics producer price index for two-wheel drive farm tractors. All repair costs, including any expenditures for repairs done outside the farms' shops, were converted into 1981 dollars using the index shown in Table 2. The real costs for parts and labor were totaled annually for each machine.

Data regarding pre-season preventative maintenance work on the tomato harvesters were incomplete. The shop foreman indicated that a minor overhaul was performed on the machines each winter, regardless of the age of the machine. He estimated the cost to be $16,000, in 1981 dollars. Other operators were contacted regarding their preventative maintenance practices on tomato harvesters. The frequency of overhauling varied from every year to every three years, depending on the intensity of use. The practices of the operation providing the data appear to be a medium-cost approach. Therefore, a fixed cost of $16,000 was added to each annual tomato harvester repair cost observation to reflect preventative maintenance costs in the form of a minor overhaul each winter.

There was substantial variation in the annual repair costs among the machines observed. The low and high costs for medium crawlers in 1981 dollars were $573 and $20,660. For the wheel tractors, annual repair costs ranged from $303 to $22,229. The lowest annual repair cost for combines was $1,338; the highest was $26,328. The low and high annual repair costs for tomato harvesters were $16,438 and $39,869, respectively.

As previously noted, machinery downtime, as well as repair costs, tend to increase as machines age. A limited amount of information on machinery downtime, pertaining only to incidents during 1983, was collected from the two farms which provided

Table 2. Repair Cost Index
(1981=100)

Year	Index
1971	33.0
1972	34.2
1973	35.4
1974	45.2
1975	52.6
1976	55.0
1977	58.3
1978	63.9
1979	72.2
1980	80.6
1981	100.0
1982	111.1

Source: Case study firm's annual average labor rates and prices paid for selected parts.

the repair cost data. This information, together with the cost data are presented for the four equipment items studied.

Annual tractor downtime was calculated from repair records. Downtime for each tractor repair incident was determined by adding two hours (for parts procurement and travel time for the mechanic) to the labor hours reported by the mechanic if the repair was done in the field; four hours were added to the labor hours if the tractor had to be taken into the shop to be repaired. Repair hours for preventative maintenance during the off-season were not considered to be downtime since no field operations were delayed by the scheduled maintenance. Combine and tomato harvester downtime hours were reported directly by harvesting crews.

The ranges of annual and cumulative hours for machines used in 1983 were similar to the total sample from which the repair cost data were derived. Thus, the downtime data are representative of a wide range of machine ages and levels of use. Annual downtime for crawler tractors ranged from a low of 37 hours to a high of 220 hours. The low and high downtimes for wheel tractors were 8 hours and 96 hours while downtime for combines varied from 3 to 87 hours. The low downtime observed for tomato harvesters was 23 hours; the high was 55 hours.

Estimated Repair Cost Equations

Previous studies and observed relationships form the basis for specifying repair cost equations. Farm machinery deteriorates as a result of both age and usage and farmers perform both preventative (pre-season) and breakdown maintenance. It was hypothesized that pre-season repair costs increase with cumulative machine hours and that breakdown repair costs are a function of both annual and cumulative use as reflected by hours of operation. Following previous studies, the data were fitted to the following equation form for each machine type:

$$PARC_{it} = a\, CMH^{b}_{it}\, MH^{c}_{it}\, e^{\varepsilon_{it}} \qquad (1)$$

where the it subscript denotes an observation in year t for machine i. The dependent variable (PARC) is price-adjusted, deflated, annual repair costs; it is deflated annual repair costs (in 1981 dollars), as reported by the case study farm, divided by the 1981 price of a comparable new machine (in thousands of dollars). The price adjustment in the variable PARC, which is similar to the approach taken by Larsen and Bowers (1965) and Bowers and Hunt (1970), facilitates projections of future repair costs. The explanatory variables are cumulative hours on the machine at the end of each year (CMH) and the hours that the machine was operated during the year (MH). The unexplained error is represented by e_{it}. Given the assumption that machinery prices and repair cost factors rise at the same rate, annual repair costs can be projected by calculating the value of the estimated equation and multiplying this value by the price of a new machine (in thousand dollars) for a given year. Estimated retail farm machinery prices for 1981 and 1986 are shown in Table 3.

For estimation purposes, equation (1) was converted into its natural log form:

$$\ln PARC_{it} = a^* + b \ln CMH_{it} + c \ln MH_{it} + \varepsilon_{it} \quad (2)$$

where a^* is the natural log of a. Given this specification, a 1 percent change in cumulative machine hours (CMH) causes price adjusted repair cost to increase by b percent. Similarly, a 1 percent change in annual machine hours (MH) causes price adjusted repair cost to increase by c percent.

The estimated annual repair cost equations by machine type are presented in Table 4. The F-statistics are all significant at the 1 percent level, indicating that the explanatory variables do have an influence on the mean of PARC. Each of the estimated coefficients has the expected positive sign, all are significantly different from zero at the 10 percent level, and most are significantly different from zero at the 1 percent level of significance. The coefficients of determination (R^2) indicate that 58 to 81 percent of the sample variation in annual repair costs can be attributed to variation in annual and cumulative machine hours.

The estimated coefficient for annual machine hours was insignificant in the combine repair cost equation and was eliminated from that equation. Lack of significance for this variable is not surprising given that there was limited variation in annual machine hours for combines. The estimated coefficients (b) for cumulative machine hours are positive for all machines, indicating that annual repair costs increase with cumulative use, as expected. The values of the coefficients indicate the relative sensitivity of annual repair costs to cumulative use. Annual

Table 3. New Farm Machinery Prices

Machinery	Retail Price by Year 1981	1986
Medium crawler tractor (diesel)	95,000	110,000
Wheel tractor (2-wheel drive diesel, 120 PTO HP)	40,000	65,000
Grain combine (self-propelled, 16 foot)	72,000	90,000
Tomato harvester (electronic eye)	155,000	175,000

Table 4. Estimated Annual Repair Cost Relationships by Machine Type*

Machine Type	Variables: Constant	Variables: CMH	Variables: MH	Summary Statistics[a]: R^2	Summary Statistics[a]: F-statistic	Summary Statistics[a]: N[b]
Medium crawler tractor	-6.1490[c] (-3.17)	.8167[c] (6.53)	.4626[d] (1.64)	.58	31.70	48
Wheel tractor	-1.8055[c] (-4.59a)	.5938[c] (19.29)	.2740[c] (4.63)	.64	260.84	299
Grain combine	-3.5861[c] (-5.48)	1.0776[c] (12.19)	---	.81	148.63	36
Tomato harvester	.9569 (1.13)	.1257[d] (1.75)	.4959[c] (3.55)	.71	11.03	12

*All of the variables are in natural log form. The dependent variable is the natural log of price-adjusted annual repair costs, in 1981 dollars (repair costs divided by new machine price, in thousands).

Table 5. Estimated Downtime Rate Relationships by Machine Type*

Machine Type	Variables: Constant	Variables: Lagged Cumulative Machine Hours	Summary Statistics[a]: R^2	Summary Statistics[a]: F-statistic	Summary Statistics[a]: N[b]
Medium crawler tractor	-3.8557[c] (-21.02)	.0001148[c] (5.82)	.79	33.86	11
Wheel tractor	-3.9967[c] (-37.20)	.0001872[c] (9.11)	.73	83.04	32
Grain combine	-4.3058[c] (-23.92)	.0005401[c] (8.11)	.67	65.77	34
Tomato harvester	-2.5854[c]	.0003022[c]	.52	8.72	10

*The dependent variable is the natural log of the annual downtime rate (annual downtime hours divided by annual use). The constant is in natural log form.

[a]t-statistics are in parentheses.

[b]Sample size.

[c]The estimated coefficient is significantly different from zero at the 1 percent level of significance.

[d]The estimated coefficient is significantly different from zero at the 10 percent level of significance.

repair costs for tomato harvesters are least sensitive, and costs for grain combines are most sensitive to cumulative use. These results are not surprising given the substantial preventative maintenance associated with tomato harvesters and the complexity of grain combines. The positive estimated coefficients for annual machine hours (c) for crawler tractors, wheel tractors and tomato harvesters indicate that annual repair costs for these machines increase as annual use increases.

Estimated Downtime Equations

The downtime (hours not available for fieldwork due to a breakdown) for a given equipment item is expected to increase with the age of the item as measured by cumulative hours of use. As suggested by the theoretical literature (Amstadter, 1973), the machine downtime rate is specified as as an exponential function of the cumulative machine hours. The equation used is:

$$DT_{it}/MH_{it} = ae^{(bCMHL_{it-1} + \varepsilon_{it})} \qquad (3)$$

where the it subscript denotes an observation for machine i in year t, DT is the annual hours of downtime, MH is annual machine hours, and CMHL is cumulative machine hours lagged one year. Given this specification, the downtime rate (hours of downtime per hour of use) changes at a constant rate b with cumulative machine hours. Downtime will equal zero if the machine is not used.

For estimation purposes, equation (3) was converted to its natural log form:

$$\ln (DT_{it}/MH_{it}) = a^* + b\ CMHL_{it-1} + \varepsilon_{it} \quad (4)$$

where a* is equal to the natural log of a.

Results of estimating equation (4) for the downtime data are presented in Table 5. All of the estimated coefficients have the expected positive sign and are statistically significant at the 1 percent level. The F-statistics are all significant at the 1 percent level, indicating that the explanatory variables do have an influence on the mean downtime rate. The percentage of variation of the downtime rate explained by cumulative machine hours (R^2) varies from .52 to .79. This result was better than expected given the small sample sizes and the approximate nature of the downtime measurements for some machinery.

As expected, annual downtime per hour of use increases at an increasing rate as lagged cumulative hours increase. The relative downtime sensitivities of the machines to cumulative use are, in descending order: combines, tomato harvesters, wheel tractors and crawler tractors. These results are as expected since harvesting machines have more complex parts which are susceptible to failure than do tractors.

The relative downtime sensitivities are not the same as the relative repair cost sensitivities, nor need they be. The repair costs include both pre-season and in-season repairs while downtime is associated only with in-season repairs.

Repair Cost and Downtime Projections by Level of Use

The effects of varying levels of use on estimated repair costs for medium crawler tractors, wheel tractors, grain combines and tomato harvesters are examined in this section. Repair cost estimates are presented for low, average and high levels of annual use. The range of use, as well as the average for each equipment item, was selected as representative of the case study farms, but also considered use rates for southwestern farms as reported by Krenz (1985). Average annual use levels for both medium crawler and wheel tractors are 1,200 hours with high and low levels calculated as plus and minus 50 percent of the average, or 600 and 1800 hours annually. Estimated tractor repair costs were truncated at 12,600 hours (seven years) at high use levels to avoid extrapolations far beyond the range of case study data and expected tractor lives. Low, average and high use levels for combines are 400, 500 and 600 hours annually while similar use levels for tomato harvesters are 200, 400 and 600 hours annually. The maximum cumulative number of hours for which estimated repair costs are presented for combines and tomato harvesters is 5400 hours.

The estimated equations reported in Table 4 were converted from their natural log forms to calculate price-adjusted repair costs. The following transformed equations were used to estimate annual repair costs (ARC) in 1986 dollars, where PR86 is the price of the new machine in 1986:

Medium crawler tractor:

$$ARC=.0021(PR86)\,(CHM)^{.8167}(MH)^{.4626}$$

Wheel tractor:

$$ARC=.1644(PR86)\,(CMH)^{.5938}(MH)^{.2740}$$

Grain combine:

$$ARC = .0277(PR86)\,(CMH)^{1.0776}$$

Tomato harvester:

$$ARC=2.604(PR86)(CMH)^{.1257}(MH)^{.4959}$$

Farm machinery prices for 1986 are reported in Table 3.

The estimated equations presented in Table 5 were converted from their natural log forms to determine estimated downtime rates. The following equations were used to calculate annual downtime hours for varying levels of use, where e is the base of the natural log system with a value of 2.71828:

Medium crawler tractor:

$$DT =.0212\,(MH)\,e^{.0001148\ CMHL}$$

Wheel tractor:

$$DT = .0184\,(MH)\,e^{.0001872\ CMHL}$$

Grain combine:

$$DT = .0135\,(MH)\,e^{.0005401\ CMHL}$$

Tomato harvester:

$$DT = .0754\,(MH)\,e^{.0003022\ CMHL}$$

Estimated annual and cumulative repair costs together with estimated annual downtime for the machines are reported by level of use in Tables 6 through 9. All costs are expressed in 1986 dollars. The tabled values for repair costs and downtime hours are expected values; the estimated relationships did not explain 100 percent of the variation in repair costs and downtime.[1]

Annual repair costs for a medium crawler tractor are low relative to the

1. As is the usual practice with the estimation of exponential functions, it is assumed that the error term of the estimated function is normally distributed with an expected value of zero. If the expected value of the error term is not zero, use of the log form equations to estimate expected annual repair costs and downtime will yield estimates of a conventional median function instead of a mean function (Goldberger, 1968). Either of these measures of central tendency is regarded as satisfactory for this study, given the case study nature of the data.

Table 6. Estimated Medium Crawler Tractor Repair Costs and Downtime by Use Level[a]

Year	Cumulative Machine Hours	Annual Repair Costs	Cumulative Repair Costs	Cumulative Repair Costs Per Hour Use	Annual Downtime Hours
Low Use - 600 hours annually					
1	600	827	827	1.38	13
2	1,200	1,457	2,285	1.90	14
3	1,800	2,029	4,314	2.40	15
4	2,400	2,567	6,881	2.87	16
5	3,000	3,080	9,961	3.32	17
6	3,600	3,575	13,535	3.76	18
7	4,200	4,054	17,590	4.19	19
8	4,800	4,521	22,111	4.61	21
9	5,400	4,978	27,088	5.02	22
10	6,000	5,425	32,513	5.42	24
Average Use - 1200 hours annually					
1	1,200	2,008	2,008	1.67	25
2	2,400	3,537	5,545	2.31	29
3	3,600	4,926	10,471	2.91	34
4	4,800	6,230	16,701	3.48	38
5	6,000	7,476	24,177	4.03	44
6	7,200	8,676	32,853	4.56	51
7	8,400	9,840	42,693	5.08	58
8	9,600	10,974	53,667	5.59	67
9	10,800	12,082	65,749	6.09	77
10	12,000	13,168	78,917	6.58	88
High Use - 1800 hours annually					
1	1,800	3,347	3,374	1.87	38
2	3,600	5,942	9,316	2.59	47
3	5,400	8,275	17,590	3.26	58
4	7,200	10,466	28,056	3.90	71
5	9,000	12,558	40,615	4.51	87
6	10,800	14,575	55,189	5.11	107
7	12,600	16,530	71,719	5.69	132

[a]Based on equations presented in Tables 4 and 5. All costs are in 1986 dollars.

Table 7. Estimated Wheel Tractor Repair Costs and Downtime by Level of Use[a]

Year	Cumulative Machine Hours	Annual Repair Costs	Cumulative Repair Costs	Cumulative Repair Costs Per Hour Use	Annual Downtime Hours
Low Use - 600 hours annually					
1	600	2,752	2,572	4.59	11
2	1,200	4,154	6,906	5.76	12
3	1,800	5,285	12,191	6.77	14
4	2,400	6,269	18,460	7.69	15
5	3,000	7,157	25,617	8.54	17
6	3,600	7,976	33,592	9.33	19
7	4,200	8,740	42,332	10.08	22
8	4,800	9,461	51,794	10.79	24
9	5,400	10,147	61,940	11.47	27
10	6,000	10,802	72,742	12.12	30
Average Use - 1200 hours annually					
1	1,200	5,026	5,026	4.19	22
2	2,400	7,585	12,611	5.25	28
3	3,600	9,650	22,261	6.18	35
4	4,800	11,448	33,709	7.02	43
5	6,000	13,070	46,779	7.80	54
6	7,200	14,565	61,344	8.52	68
7	8,400	15,961	77,305	9.20	85
8	9,600	17,279	94,584	9.85	106
9	10,800	18,531	113,114	10.47	133
10	12,000	19,727	132,841	11.07	167
High Use - 1800 hours annually					
1	1,800	7,141	7,151	3.97	33
2	3,600	10,777	17,918	4.98	46
3	5,400	13,711	31,628	5.86	65
4	7,200	16,265	47,893	6.65	91
5	9,000	18,569	66,462	7.38	127
6	10,800	20,692	87,154	8.07	179
7	12,600	22,676	109,830	8.72	250

[a]Based on equations presented in Tables 4 and 5. All costs are in 1986 dollars.

Table 8. Estimated Grain Combine Repair Costs and Downtime by Level of Use[a]

Year	Cumulative Machine Hours	Annual Repair Costs	Cumulative Repair Costs	Cumulative Repair Costs Per Hour Use	Annual Downtime Hours
Low Use - 400 hours annually					
1	400	1,587	1,587	3.97	5
2	800	3,350	4,938	6.17	7
3	1,200	5,186	10,124	8.44	8
4	1,600	7,071	17,195	10.75	10
5	2,000	8,993	26,188	13.09	13
6	2,400	10,946	37,134	15.47	16
7	2,800	12,923	50,057	17.33	20
8	3,200	14,924	64,981	20.31	25
9	3,600	16,943	81,924	22.76	30
10	4,000	18,980	100,904	25.23	38
Average Use - 500 hours annually					
1	500	2,019	2,019	4.04	7
2	1,000	4,261	6,280	6.28	9
3	1,500	6,596	12,876	8.58	12
4	2,00	8,993	21,869	10.93	15
5	2,500	11,438	33,307	13.32	20
6	3,000	13,921	47,228	15.74	26
7	3,500	16,437	63,664	18.19	34
8	4,000	18,980	82,645	20.66	45
9	4,500	21,549	104,194	23.15	59
10	5,000	24,140	126,814	25.36	77
High Use - 600 hours annually					
1	600	2,457	2,457	4.10	8
2	1,200	5,186	7,643	6.40	11
3	1,800	8,028	15,671	8.71	15
4	2,400	10,946	26,617	11.09	21
5	3,000	13,921	40,538	13.51	30
6	3,600	16,943	57,481	15.97	41
7	4,200	20,005	77,486	18.45	57
8	4,800	23,101	100,587	20.96	78
9	5,400	26,227	126,814	23.48	108

[a]Based on equations presented in Tables 4 and 5. All costs are in 1986 dollars.

Table 9. Estimated Tomato Harvester Repair Costs and Downtime by Level of Use[a]

Year	Cumulative Machine Hours	Annual Repair Costs	Cumulative Repair Costs	Cumulative Repair Costs Per Hour Use	Annual Downtime Hours
Low Use - 200 hours annually					
1	200	12,272	12,272	61.36	17
2	400	13,390	25,662	64.16	19
3	600	14,090	39,752	66.25	20
4	800	14,609	54,361	67.95	22
5	1,000	15,024	69,385	69.39	24
6	1,200	15,373	84,758	70.63	27
7	1,400	15,673	100,431	71.74	29
8	1,600	15,939	116,370	72.73	32
9	1,800	16,176	132,546	73.64	35
10	2,00	16,392	148,938	74.47	39
Average Use - 400 hours annually					
1	400	18,882	18,882	47.21	25
2	800	20,601	39,483	49.35	29
3	1,200	32,678	61,162	50.97	34
4	1,600	22,477	83,638	52.27	38
5	2,000	23,116	106,754	53.38	44
6	2,400	23,652	130,406	54.34	51
7	2,800	24,115	154,521	55.19	58
8	3,200	24,523	179,044	55.95	67
9	3,600	24,889	203,933	56.65	77
10	4,000	25,220	229,153	57.29	88
High Use - 600 hours annually					
1	600	24,295	24,295	40.49	45
2	1,200	26,506	50,801	42.33	54
3	1,800	27,892	78,693	43.72	65
4	2,400	28,919	107,613	44.84	78
5	3,000	29,742	137,355	45.79	93
6	3,600	30,432	167,787	46.61	112
7	4,200	31,027	198,814	47.34	134
8	4,800	31,552	230,366	47.99	161
9	5,400	32,023	262,389	48.59	193

[a]Based on equations presented in Tables 4 and 5. All costs are in 1986 dollars.

machine's purchase price. They rise with cumulative use, but at a decreasing rate. With average use, annual repair costs increase from $2,008 the first year to $13,168 in the tenth year. With low use (600 hours annually), they are approximately 59 percent below what they would be with average use; conversely, high use (1800 hours annually) raises the costs by approximately 68 percent. Note that average cumulative repair costs for a given level of cumulative hours will decrease as the level of annual use increases. For example, the cumulative average repair cost for a medium crawler used a cumulative total of 3600 hours, is $3.76 per hour when used 600 hours per year, $2.91 per hour when used 1200 hours per year, and $2.59 per hour when used 1800 hours annually (Table 6).

Estimated annual downtime for medium crawlers remains relatively low during the 10 year period. It is less than 10 percent of annual use for all of the values listed (Table 6). These downtime and repair cost projections indicate that medium crawler tractors are durable and long-lived machines. It seems reasonable to expect a crawler tractor to provide service without unduely high repair costs or downtime for 10 years at average use levels specified in this study.

Annual repair costs for wheel tractors are higher than those for medium crawler tractors, given identical levels of use (Table 7). Estimated annual wheel tractor repair costs almost quadruple between the first and tenth years at average use levels. With low use (600 hours per year), annual repair costs are approximately 45 percent below what they would be with average use. With high use (1800 hours per year), estimated repair costs increase some 42 percent over the estimate for average use. Cumulative repair costs exceed the purchase price of a new machine during the seventh year of average use.

Wheel tractor downtime also rises more rapidly with cumulative use than does crawler tractor downtime. By the ninth year of average use and the seventh year of high use, downtime exceeds 10 percent of annual hours. While the expected life of wheel tractors subject to average use is 10 years, they are unlikely to last more than seven years at the high levels of use observed on the case study farms.

Estimated cumulative average hourly repair costs for combines are greater than for either crawler or wheel tractors but are less than the costs for tomato harvesters. Annual repairs with low use are 21 percent below repair costs with average use, while the converse is true with high use. Cumulative repair costs exceed the purchase price of a new combine by the eighth year of average use. There are some efficiencies in hourly combine repair costs associated with level of use. Estimated average repair costs per hour of use for 4000 hours of low annual use are $25.23 while comparable costs for 4000 hours of average annual use are $20.66. Similar comparisons can be made in Table 8.

The reliability of combines deteriorates more rapidly than that of the tractors. Downtime exceeds 10 percent of annual use by the eighth year of average use (500 hours annually). It is not unreasonable to expect a combine to last 10 years given average levels of use, but the lifetime for high levels of use will probably be less than nine years, based on the machine ages for the case study farms.

Annual repair costs for tomato harvesters do not increase substantially with cumulative use because of the high level of annual preventative maintenance that these machines receive. Nevertheless, they are affected by the level of annual use. Low use machines have annual repair costs which are approximately one-third less than those of average use machines; conversely, repair costs for high use machines are one-third higher. Since the preventative maintenance costs are substantial, estimated cumulative repair costs exceed the purchase price of a new machine by year eight with average use, by year seven with high use. In terms of cumulative average repair costs per hour of operation, a tomato harvester used 400 hours per year for 10 years would have estimated average repair costs of over $57 per hour (Table 9). The impact of annual preventative maintenance on estimated repair costs per hour of operation for different annual use levels are significant. For example, the estimated repair costs for a tomato harvester used a total of 2000 hours at low use (200 hours annually) are $74.47 per hour, while at average use (400 hours per year) estimated repair costs are $53.38 per hour. Table 9 does not include an estimate for 2000 hours at high use levels, but hourly repair costs would be slightly less than the $44.84 estimate for 2400 hours (four years) of use.

Despite these preventative maintenance efforts, tomato harvester downtime does rise rapidly with cumulative use. By the third year of high use, downtime is likely to exceed 10 percent of annual use. Tomato harvesters are costly to operate; they have high repair costs and short lifetimes relative to other farm machinery with high purchase prices, such as crawler tractors.

Summary

Farm machinery is an important and expensive factor of production for commercial farms. A 120 h.p. wheel tractor can cost $65,000 or more while a new tomato harvester now costs $175,000. Repair costs for parts and labor are also high, accounting for some 7.3 percent of total operating expenses for farm firms in 1985. There are also important costs associated with breakdowns which may not be included in cash operating expenses; for example: idle labor; lost crop revenue when breakdowns prevent timely planting, pest control applications or harvesting; and injuries to workers.

Farmers continuously face repair vs. replacement decisions for farm machinery. While information on many of the variables which enter such a decision are readily available (new equipment price, salvage value of old equipment, depreciation rules, tax incentives, and interest rates), data on expected repair costs by level of use and downtime are not. This report assembles data from two large San Joaquin Valley farms on annual repair costs and downtime for four large equipment items: medium crawler tractors, wheel tractors, grain combines and tomato harvesters.

While these study results cannot be

generalized to all California farms, they do provide an indication of the nature and magnitude of repair costs and downtime as related to annual and cumulative use for the four equipment items. Estimates for 1986 indicate that annual repair costs increase each year for a given level of use. Repair costs per hour of operation for a wheel tractor with average use (1,200 hours per year), for example, increase from $4.19 per hour during the first year to $16.44 per hour during the tenth year with a cumulative average of $11.07 per hour over the total 10 year period. Estimated annual downtime for a wheel tractor with average use increased from 22 hours the first year to 167 hours in the tenth. The pattern of increases for repair costs per hour of operation and downtime are similar for other equipment items. Cumulative repair costs (in 1986 dollars) per hour of operation for average levels of use over 10 years for the equipment items analyzed were: medium crawler tractors, $6.58 per hour; wheel tractors, $11.07 per hour; combines, $25.36; and tomato harvesters, $57.29 per hour.

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