7. RELATIONSHIP OF COST AND USAGE

CHAPTER OBJECTIVES:

- ***To introduce the reader to the relationship between machinery use and machinery cost;***
- ***To describe the influence of machinery size on machinery cost;***
- ***To explain the structure of a model that predicts machinery repair cost;***
- ***To discuss the relevance of cost predictions by examples;***
- ***To validate the relationship of repair cost and usage.***

Repair cost is a small but important portion of total machinery cost. Because it tends to increase with machine size and age, repair cost become important in influencing machinery management. In order to obtain a uniform procedure for machinery cost analysis, the farmer must determine the size of the machinery he wants to use and apply a reliable model for predicting repair cost.

Repair cost was normally reported as a percentage of the purchase price of the machine and no attempt was made at relating this cost to machine size or age. Repair cost tends to increase with machine size while the timeliness cost decrease.

In the first year of ownership, repair cost is nearly zero, as most repairs would be covered by a warranty. As age increases, more repairs are needed. When the machine approaches the end of its life, repair cost tends toward a constant annual value. This does not mean that a huge fleet of machinery that is being replaced regularly will be the best economical machinery system. From a cost point of view, there is certainly an optimum fleet size that goes with individual machinery size. By knowing the influence of machinery size and knowing the relationship between repair cost and usage, the farmer will be able to manage his machinery in an economical way.

7.1. MACHINERY SIZE

After calculating the rate of work needed, as described in Chapter 4, the farmer must decide how many machines, and what size, to select. He must have sufficient capacity to complete the operation within a certain time frame. A higher capacity machine will give greater timeliness but this benefit gradually becomes less because larger machinery normally results in higher fixed cost. Figure 7.1 shows the relationship between the different cost components and machinery size.

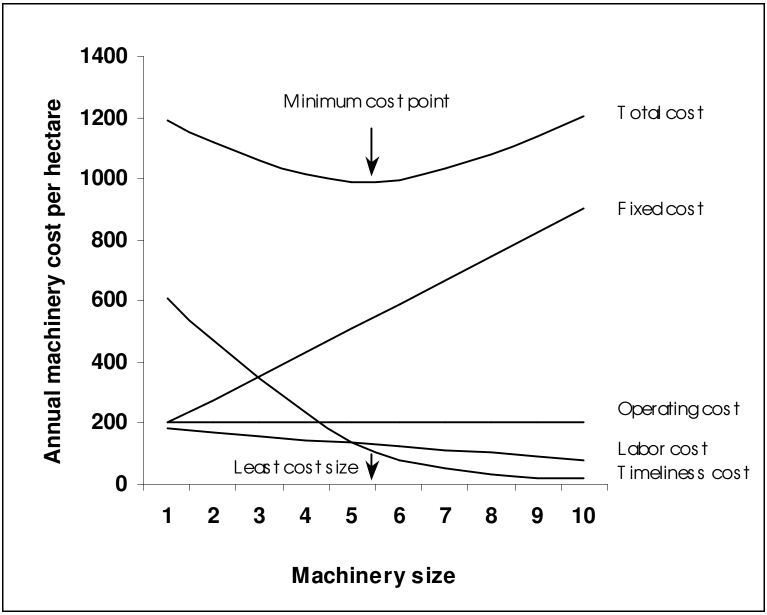

FIGURE 7.1: EFFECT OF INCREASING MACHINERY SIZE ON MACHINERY COST

According to figure 7.1, the per hectare cost of timeliness and labor decrease as machinery size increases. Operating cost stays the same while fixed cost rise quite dramatically. For very small machinery (relative to crop size) a slight increase in machinery size may lower timeliness cost significantly, enough to more than offset the higher fixed cost. However, as machinery size continues to increase, the savings on timeliness cost diminish, and eventually total cost begin to rise. The end result is that total machinery cost will decrease up to a point where the optimum balance between the different cost components exists after which it will increase again. Therefore, optimum machinery size will be at that point where total cost is the lowest.

In practice, however, both capital and labor have varying opportunity cost according to their availability. Decisions regarding machinery size therefore cannot be separated from the total planning of the farm business. In choosing the number and size of machinery required for a farm, the farmer must consider labor supply, capital availability and timeliness.

7.2. RELATIONSHIP OF COST AND USE

In order to obtain a uniform procedure for machinery cost analysis, a standard model for repair cost is desirable. Many repair cost models had already been published in numerous journals but several problems exist with the results. This cause confusion as to which model to use because there are more than one model for the same machine and in some, age is based upon area covered while other are based on hours used.

Another concern is that repair cost relationship were determined from a very small sample and as a result, predicted repair cost from these models are sometimes inconsistent. A standardized model that can accurately predict the trend in cost over the life of the machine can assist the farmer to manage his machinery in an economical way.

7.2.1. BACKGROUND

A thorough investigation into developing a standardized model to predict repair cost was prompted by:

- Suspicion of the traditional approach of basing estimates of repair and maintenance cost on a constant percentage of the purchase price or on fuel consumption;
- The influence of management policies and operator skills;
- An increasing tendency to extend normal tractor life by means of a major overhaul or re-conditioning;

- Management policies and operator skills in different countries that are assumed not to be of the same standard as the samples on which other model parameters are based;
- Different soil and climatic conditions;
- Different types of farming.

Following a thorough literature survey, the Institute for Agricultural Engineering of the Agricultural Research Council in South Africa, decided to base their analysis on the power function model proposed by Alan Rotz* in 1986. The objective was to develop model parameters for the Rotz model, incorporating the influence of management policy, operator skills and other factors, where appropriate.

7.2.2. METHODOLOGY

Data was collected from farmers and farm businesses that kept accurate records of repair and maintenance cost in eight regions over South Africa. This represented various soil conditions and farming types including horticulture, cattle, fruit and agronomic farming.

A sample of 238 tractors having operated less than 12,000 hours (First life tractors) and a sample of 44 tractors having been re-conditioned or overhauled (Second life tractors) was collected. A statistical computer program (Stat Graphics) was used to perform the regression based on the Rotz model, analyzing the first life and second life tractors separately. Where sufficient reliable data could not be collected on a particular type of machine, the model parameters were estimated from other closely related machines with the same number of moving parts or from literature data.

The power function offered an excellent relationship for cumulative repair cost over the first life span, but a linear function was best suited over the second life span. The collected data for each machine was adjusted according to conditions observed on the farms during the surveys, in terms of management practices and operator skills etc. as listed in Table 7.1 below. The actual yearly costs,

* *C Allen Rotz, 1986: A Standard Model for Repair Costs of Agricultural Machinery, ASAE Paper No 85-1527.*

expressed as percentage of the list price of an identical or equivalent machine for that year, was divided by the compensating factor to arrive at an ideal cost figure representing a well-maintained machine.

The compensated cumulative cost figure for a machine after **n** years was calculated as:

$$C'=1/F(R_1/L_1 + R_2/L_2 + - - - - R_n/L_n) \quad [7.1]$$

Where:

- **C'** = Cumulative cost after **n** years, as fraction of a representative list price;
- **F** = External influential factors such as management policy and operator skills (**F** = 1 for ideal conditions);
- **n** = Operating age in years;
- **i** = Year number under consideration;
- **R** = Repair and maintenance cost recorded for the year;
- **L** = List price prevailing for the year.

This compensated value for **C'**, recalculated per thousand hours, as

$$C'' = C' / (\text{Accumulated hours}) \times 1\,000 \quad [7.2]$$

served as input for the regression in the formula:

$$C'' = mH^d \quad [7.3]$$

Where:

- **C"** = Cumulative cost as fraction of the prevailing list price of an identical or equivalent machine at the end of the period under consideration, equated to **C"** in formula [7.2];

- **m** = Model parameter reflecting the magnitude of the costs;
- **H** = Cumulative machine operating hours in thousands;
- **d** = Model parameter reflecting the cost distribution over the machine life span.

Note:

- The prevailing list price of the machine is suggested to take the influence of inflation into account;
- The regression was based on mean expenditure for machines, grouped into 1,000-hour intervals of operation.

7.2.3. MODEL STRUCTURE

The total life of a machine can normally be divided in a *first life* and a *second life*. The difference between the two is that the end of the first life is normally characterized by a major overhaul. After this, the machine enters a *second life*. Both these phases must be taken into account by the model.

First life

The model relates repair and maintenance cost to operating hours over the first life of a machine by the formula:

$$C = F \times m \times H^{d} \times L$$

[7.4]

Where:

- **C** = Cumulative cost as fraction of the prevailing list price of an identical or equivalent machine;
- **H** = Cumulative machine operating hours in thousands,

- **F** = External influential factors such as management policy and operator skills;
- **F** = $\mathbf{f_a}$ x $\mathbf{f_b}$ x etc. as appropriate according to Table 7.1, (F = 1 for ideal conditions),
- **m** = Model parameter reflecting the magnitude of the costs;
- **d** = Model parameter reflecting the cost distribution over the machine's first life span.
- **L** = List price prevailing for the year.

Second life

Using formula 7.4 and adapting it to predict the constant rate of repair and maintenance cost after the major overhaul, the following relation is suggested:

$$C2 = F \times m \times H_1^{(d-1)} \times L \qquad [7.5]$$

Where:

- **C2** = Average cost per 1,000 hours as fraction of the prevailing list price of an identical or equivalent machine;
- $\mathbf{H_1}$ **=** Total first life span in thousands of hours and **F, m** and **d** as for formula 7.4.
- **L** = List price prevailing for the year.

Note:

- Formula 7.5 expresses the repair and maintenance cost as an average cost per thousand hours and not cumulative as formula 7.4 does.

7.2.4. MODEL PARAMETERS

The model arrived at a number of parameters. These parameters can have a further influence on the repair cost.

Management and Skills parameter F

Parameter **F** is calculated as the product of individual compensating factors **f** as in Table 7.1, related to the circumstances under which the machine is operated:

$$F = f_a \times f_b \times \ldots$$

as applicable according to the listed conditions deviating from the ideal situation conducive to good maintenance.

[7.6]

TABLE 7.1: COMPENSATING FACTORS FOR DEVIATIONS FROM IDEAL CONDITIONS IN PREDICTING REPAIR AND MAINTENANCE COST

Case	Factor f	Deviating Condition
a	1.15	Machine operator not appropriately trained and not involved in basic daily maintenance
b	1.15	Lack of management and supervision by owner or manager
c	1.15	Machine allocated to various operators
d	1.5	*Bad model* in manufacturer range. (A rare occurrence)
e	1.5	Tractor over ballasted outside of manufacturers specifications and operated like this for an extended period

Table 7.1 indicates that factors like the operator, management, bad models or ballasting can have a further influence on repair cost.

Magnitude and Distribution parameters m and d

Parameter **m** determines the magnitude of the repair cost over the period under consideration whilst parameter **d** determines the distribution of the cost over the machine's life span. A larger value of **d** indicates that the repair cost would be concentrated towards the end of the life span.

Table 7.2 lists the values for parameters **m** and **d** as well as the estimated first life span and typical yearly usage for different machines as surveyed. It is suggested that the cost figure for the second life should not be estimated beyond two-thirds of the life span for the first life.

TABLE 7.2: MAGNITUDE AND DISTRIBUTION PARAMETERS FOR REPAIR AND MAINTENANCE COST

Machine	First life span	Typical yearly usage	Cost parameter	
	H_1		m	d
	(hours)	(hours)		
Tractors				
2-Wheel drive	12 000	1 000	0.015	1.6
4-Wheel drive	12 000	1 000	0.015	1.6
Ground engaging				
Mould board ploughs	2 500	250	0.245	1.6
*Disc harrows, offset	2 500	250	0.138	1.6
Disc harrows, tandem	2 500	250	0.138	1.6
*Chisel ploughs	2 500	250	0.166	1.2
Cultivators, field	2 500	250	0.200	1.2
*Sub-soilers, narrow sheer	3 000	300	0.107	1.2
*Rotary hoe	2 000	200	0.303	1.4
*Cultivators, row crop	2 500	250	0.277	1.4
Rotary tiller	2 000	250	0.231	1.6
Sub-soilers, wide sweep	3 500	350	0.189	1.2

Planting				
Planters, row crop, mounted	1 200	120	0.598	1.6
*Planters, row crop, trailed	1 500	150	0.418	1.6
Planters, wheat	1 500	150	0.418	1.6
Harvesting and hay making				
Threshers	2 000	200	0.165	1.6
Combines, trailed	3 000	300	0.078	1.6
*Combines, self propelled	3 000	300	0.048	1.6
*Mowers, drum	2 000	150	0.283	1.5
*Mowers, cutter bar	2 000	150	0.424	1.5
*Mower, disc & conditioner	2 000	200	0.212	1.5
*Rake, side delivery	2 000	200	0.522	1.2
*Baler, square bale	2 000	200	0.198	1.6
Baler, round bale	2 000	200	0.198	1.6
Slasher	3 000	300	0.283	1.5
*Forage harvesters	2 000	200	0.263	1.6
*Trailer, single axle, transfer	3 500	250	0.069	1.4
Bean puller-windrower	2 000	200	0.218	1.2
Groundnut lifter	2 000	200	0.198	1.6
Potato lifter	2 000	200	0.198	1.6
Miscellaneous				
Fertilizer spreader	1 200	150	0.723	1.2
*Sprayer, boom	1 500	150	0.307	1.2
Sprayer, air carrier	1 500	150	0.283	1.4
Trailers, 2-axle	10 000	500	0.025	1.2
*Stubble choppers	2 000	200	0.130	1.2
***Field survey results**				

Table 7.2 shows the magnitude and distribution of repair and maintenance cost over the lifetime of agricultural machinery. These factors can be used to draw graphs of the relationship between repair cost and machinery usage.

7.3. MODEL APPLICATION

Formula 7.4 is used to predict the costs for a machine during its first life only. Note that the cumulative cost over a specified period is calculated. The cost at the start and end of the period should be calculated and subtracted from each other to arrive at the cost for the particular period alone.

Formula 7.5 predicts the cost per 1,000 hours of operation, based on the average cost for the machine over its first life span. The cost for the particular period is then calculated on a pro-rata basis for the number of operating hours selected. It is suggested that the predicted second life of a machine be limited to two-thirds of the first life span.

Note:

- The cost involved in the major overhaul is not incorporated in formula 7.5.

The formulas and principles discussed above can be demonstrated by examples.

EXAMPLE 1:

Predict the repair and maintenance cost for a tractor for the forthcoming season if the expected operating hours for the season would be 800 hours. The tractor has already accumulated 7,000 hours. Bear in mind that although sound management is practiced, the tractor is not allocated to one operator alone and the operators are not specially trained. The present list price for an equivalent tractor is $125,000.

Formula 7.4 is applicable:

$$C = F \times m \times H^{d} \text{ (As fraction of the present list price)}$$

From Table 7.1, a = 1.15 and c = 1.15

$$\begin{aligned} F &= a \times c \\ &= 1.3225 \end{aligned}$$

From Table 7.2, m = 0.015 and d = 1.6

Cumulative costs over 7,000 hours:

$$\begin{aligned} C_7 &= 1.3225 \times 0.015 \times (7)^{1.6} \times \$125{,}000 \\ &= \$55{,}790 \end{aligned}$$

Cumulative costs over 7,800 hours:

$$C_{7.8} = 1.3225 \times 0.015 \times (7.8)^{1.6} \times \$125{,}000$$

= \$66,336

Net costs for the forthcoming 800 hours:

$$= C_{7.8} - C_{7-}$$
= \$10,546

EXAMPLE 2:

The tractor above was overhauled at 12,000 hours. Now predict the repair and maintenance cost for the next 800 hours.

Formula 7.5 is applicable:

$$CC2 = F \times m \times H_1^{(d-1)} \text{ (As fraction of the present list price)}$$

Parameters **F, m** and **d** are applicable as above but $\mathbf{H_1}$ = 12 (12,000 hours life span):

$$C2 = 1.3225 \times 0.015 \times (12)^{0.6} \times \$125,000$$
$$= \$11,013$$

(Only valid for a second life period of 8 000 hours, being ° x 12,000 hours)

7.4. VALIDATION OF THE MODEL

The validity of the model is illustrated in figures 7.2 to 7.4.

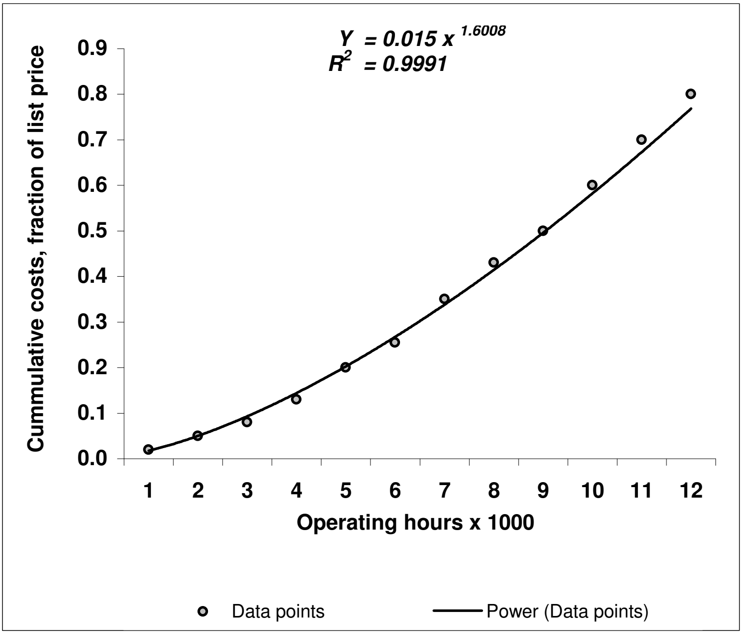

FIGURE 7.2: POWER LAW REGRESSION OF TRACTOR REPAIR AND MAINTENANCE COST FOR THE FIRST LIFE (SAMPLE SIZE: 238 TRACTORS)

Figure 7.2 illustrates the regression achieved using the power law for tractors before the first major overhaul after a typical 12,000 hours of operation (First life), using formula 7.4: $\mathbf{C = F \times m \times H^{d}}$.

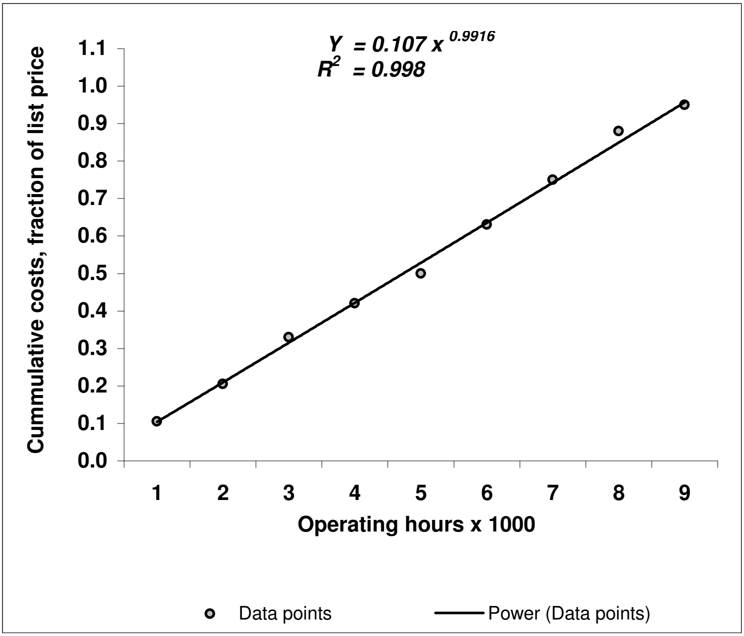

FIGURE 7.3: POWER LAW REGRESSION OF TRACTOR REPAIR AND MAINTENANCE COST FOR THE SECOND LIFE (SAMPLE SIZE: 44 TRACTORS)

When applying the power law of formula 7.5 to the period after the first major overhaul (Second life), as in Figure 7.3, totally different parameter values for **m** and **d** result. The approach of exponent **d** towards unity suggests that a linear relationship between cumulative costs and operating hours exists.

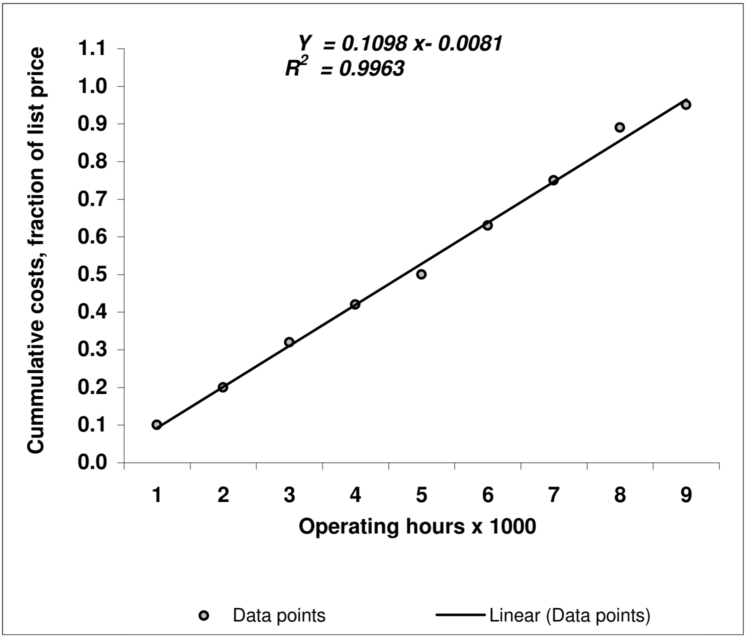

FIGURE 7.4: LINEAR REGRESSION OF TRACTOR REPAIR AND MAINTENANCE COST FOR THE SECOND LIFE (SAMPLE SIZE: 44 TRACTORS)

The linear regression of Figure 7.4 illustrates a constant repair and maintenance cost per 1,000 hours of operation. The average cost per 1,000 hours over the first life span, which is to be applied for the second life span, is calculated using formula 7.5:

$$CC2 = F \times m \times H_1^{(d-1)}$$

with H_1 being the first life span in thousand hours.

With the assistance of the graphs in Figures 7.2 to 7.4, the relationship between repair cost and machinery use can be calculated for all types of machinery. The increased spreading of tractor repair cost is shown in Table 7.3.

TABLE 7.3: SPREADING OF TRACTOR REPAIR COST IN RELATION TO USAGE

Operating hours	Cumulative repair cost as % of the list price	Average Repair cost as % Of the list price/1000h
1000	1.50	1.50
2000	4.55	3.05
3000	8.70	4.15
4000	13.78	5.08
5000	19.70	5.92
6000	26.37	6.67
7000	33.75	7.38
8000	41.79	8.04
9000	50.45	8.66
10000	59.72	9.27
11000	69.55	9.83
12000	80.00	10.45
TOTAL		**80.00**

Table 7.3 indicates that repair cost increases over the lifetime of a tractor. The repair cost will accumulate to 80% of the list price over twelve years and to 59.72% over ten years.

A detailed list of the ten-year spread for other types of machinery is included in Table 7.4.

TABLE 7.4: SPREADING OF REPAIRS COST FOR MACHINERY IN RELATION TO USAGE OVER TEN YEARS

Machine	Annual use in hours	YEARS										
		1	2	3	4	5	6	7	8	9	10	Total
Balers	200	1.51	3.06	4.17	5.11	5.94	6.71	7.41	8.08	8.71	9.31	60.01
Bean puller	200	3.16	4.10	4.55	4.87	5.12	5.33	5.51	5.67	5.82	5.95	50.08
Chisel plow	250	3.15	4.08	4.52	4.85	5.10	5.30	5.49	5.65	5.79	5.92	49.85
Combine harvester	300	0.70	1.42	1.94	2.37	2.76	3.11	3.44	3.75	4.04	4.32	27.85
Cultivators, field	250	3.79	4.92	5.45	5.84	6.14	6.39	6.61	6.81	6.97	7.14	60.06
Cultivators, row	250	3.98	6.52	8.02	9.18	10.16	11.01	11.77	12.46	13.11	13.70	99.91
Disc harrows	250	1.50	3.05	4.16	5.09	5.92	6.68	7.40	8.03	8.68	9.27	59.78
Fertilizer spreaders	150	7.42	9.63	10.68	11.43	12.03	12.52	12.95	13.32	25.00	15.00	129.98
Forage harvesters	200	2.00	4.07	5.54	6.79	7.90	8.91	9.85	10.73	11.57	12.37	79.73
Harrows	200	7.57	9.82	10.89	11.66	12.26	12.77	13.20	13.58	13.93	14.24	119.92
Harvester	200	1.26	2.55	3.48	4.26	4.95	5.59	6.18	6.73	7.26	7.76	50.02
Harvesters, trailed	300	1.14	2.31	3.15	3.85	4.48	5.05	5.60	6.10	6.56	7.02	45.26
Mould board plows	250	2.76	5.62	7.65	9.37	10.89	12.30	13.59	14.82	15.97	17.07	110.04
Mowers, cutter bar	150	2.46	4.50	5.83	6.91	7.83	8.66	9.42	10.12	10.77	11.40	77.90
Mowers, disc cond	150	1.64	3.01	3.89	4.61	5.23	5.78	6.30	6.75	7.20	7.60	52.01
Mowers, drum	200	1.90	3.47	4.49	5.32	6.03	6.67	7.25	7.79	8.29	8.77	59.98
One toe ripper	300	2.52	3.28	3.63	3.89	4.09	4.25	4.40	4.53	4.65	4.75	39.99
Planters, row, trailed	150	2.01	4.08	5.56	6.81	7.92	8.94	9.88	10.76	11.60	12.41	79.97
Planters, rows, mnt	120	2.01	4.09	5.57	6.82	7.93	8.95	9.89	10.78	11.62	12.42	80.08
Planters, wheat	150	2.01	4.08	5.56	6.81	7.92	8.94	9.88	10.76	11.60	12.41	79.97
Potato lifters	200	1.51	3.06	4.17	5.11	5.94	6.71	7.41	8.08	8.71	9.31	60.01
Rippers	350	5.36	6.96	7.72	8.26	8.69	9.05	9.35	9.63	9.87	10.10	84.99
Rotary tiller	200	3.18	5.22	6.42	7.35	8.13	8.81	9.42	9.98	10.90	10.96	80.37
Rotevators	250	2.51	5.11	6.96	8.52	9.91	11.18	12.37	13.47	25.00	8.75	103.78
Slasher	300	4.65	8.50	11.01	13.04	14.79	16.35	17.78	19.10	20.33	21.50	147.05
Sprayers, air carrier	150	2.00	3.26	4.01	4.60	5.08	5.50	5.88	6.23	6.55	6.85	49.96
Sprayers, boom	150	3.15	4.10	4.54	4.86	5.11	5.32	5.50	5.66	5.80	5.93	49.97
Stubble choppers	200	1.88	2.44	2.71	2.90	3.05	3.18	3.29	3.38	3.47	3.55	29.85
Tractors	1000	1.50	3.05	4.15	5.08	5.92	6.67	7.38	8.04	8.66	9.27	59.72
Trailer	500	1.09	1.41	1.57	1.67	1.77	1.83	1.90	1.96	2.00	2.05	17.25
Transfer trailer	250	1.00	1.61	2.00	2.29	2.53	2.74	2.93	3.11	3.26	3.40	24.87

Table 7.4 shows the relationship between machinery use and repair cost over the life span of the most types of agricultural machinery as a percentage of its list price. These numbers can be used to calculate the annual or total repair cost of a particular machine, as long as the list price is available.

7.5. DISCUSSION

A fair sample of tractors was available for the regression over the first life span of 12,000 hours and the results can be relied upon for South African conditions. Although quite consistent, the tractor sample for the period after the first major overhaul was rather small. The results do however clearly demonstrate the deviation from the model parameters as arrived at for the first life span, favoring a linear relationship of cumulative cost over the second life span.

The applicability of the model for single operations may well be questioned, as discussed by Rotz, based on the approach that the model applies for average yearly usage. Applying factor **e** from Table 7.1 may, however, offer one approach. The application of a factor related to type of operation should be researched. Another approach may be to incorporate a figure related to specific fuel consumption to take tractor loading into account. This may prove useful when incorporated in a mechanization-planning model.

As machine reliability improves with the introduction of new technology, model parameters need to be updated on a regular basis. Modern information technologies offer the opportunity to develop an in-time database updating system to facilitate this.

7.6. CONCLUSION

Machinery size is influenced by timeliness cost and fixed cost. The availability of capital and labor will eventually determine the size of the machinery the farmer is going to use. The opportunity cost of capital and labor means that decisions regarding machinery size must be taken as part of the whole farm business.

The Allen Rotz model for predicting repair and maintenance cost for agricultural machinery was used to develop model parameters for South African conditions. An additional parameter was added to the model to account for management policy and operator skills. The type of farming and soils had no significant effect on the model parameters. Thus, the additional parameter developed for South

Africa can safely be used in other countries as well.

It was found that the repair and maintenance cost for a machine after a major overhaul differed substantially from the power law relationship with machine hours. A constant cost per 1,000 hours equal to the average over the pre-overhaul period is suggested instead.

Care must be taken not to apply the model to single operations without taking the machine load into account. No proven suggestion can be offered to compensate for this as yet. The management factor added to the Allen Rotz model may however offer some guidance in this respect.

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