TECHNICAL NOTE:

BENCHMARKING TRACTOR COSTS

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ABSTRACT. *Current (2002) price data and standard relationships for tractor costs including fuel, repair and maintenance, taxes, insurance, and housing, and capital investment were integrated to estimate tractor–specific cost ($/kWh). These estimates serve as benchmarks to determine competitiveness of new, for–sale units, as well as leased or rented units. A factorial approach was used to generate cost projections, from which empirical estimating functions were generated. With fuel included, a simple empirical function estimated specific tractor cost was within $0.0045/kWh or 0.75% of the projected value 90% of the time.*

Keywords. *Tractor, Cost, Management, Operating cost, Selection.*

The cost of machinery remains a significant portion of the cost of production of most food and agricultural crops. The cost of operating tractors as power units for many operations continues to be one of the largest input costs to farming. Algorithms and software exist to aid in minimizing machinery costs, but these optimizing selection models seem to get limited use outside of formal education settings because of their complexity; to use some of these models correctly requires adequate training and constant assurance that input variables and parameters are up–to–date.

ASAE Standard EP496.2 (2002b) includes a conceptual (and instructional) function for optimal machine size that includes timeliness, labor, tractor, and machine costs. While not a system model, this equation can help in sizing machinery more optimally. Such a function requires prorated information on the cost of power units.

Lavoie et al. (1991) developed a linear programming protocol that even incorporated soil compaction effects; however, they only included five possible tractor sizes for three different farm sizes. Rotz et al. (1983), noting that least cost approaches such as linear programming cannot match equipment (they can only select among complements of matched equipment), developed an algorithm for selecting machinery sets. They applied their model to an analysis of conservation and conventional tillage systems.

McClendon et al. (1987) reviewed several machinery selection models. They used simulation over multiple years, driven by weather data, to size machinery while considering both risk and net return. Parmar et al. (1996) also used the output from a simulation model as the objective function to optimization techniques; they used a genetic algorithm and an exhaustive search to optimally select machinery. This approach of simulation within optimization, while thorough, is computationally intensive and requires tremendous effort to set up the simulation model to adequately reflect real farms.

Siemens et al. (1990) developed, and made available, a software package that selects optimal machinery sets. It is probability–based and incorporates estimates of machine capacity, working days, power requirements, labor, and fuel usage. It allows the user to set the cropping patterns and tillage, planting, and harvesting operations to be performed. However, proper use of the model for actual decision making (beyond concept teaching) requires a substantial update of information. As Rotz et al. (1983) mentioned, farmers normally do not have an optimal machinery set at any moment because the set that has maximum utility (benefits less costs including timeliness) is a dynamic moving target. Furthermore, some aspects of tractor and implement selection are driven by personal preference rather than monetary impact. Many technological advancements have economic benefit, yet are not always selected based solely on profitability; the same is true for other aspects such as ergonomics, size, and brand.

Despite the existence of more advanced techniques of power unit costing and selection, a simpler approach to determining tractor cost was developed. The results may be valuable to other models that are more complex with regard to other issues such as compaction, environmental impact, or risk; they may also be used to help assign value to mobile power units that are rented, leased, or owned. In many cost accounting and machinery selection situations, the cost of power is needed; therefore, to facilitate optimization of machinery systems and provide simple computation of benchmarks for the agricultural industry, the objectives of this work were:

- to bring functions related to tractor costs together so comparisons of alternatives could be done easily and
- to develop a simple empirical model of tractor cost with and without fuel included.

Article was submitted for review in September 2002; approved for publication by the Power & Machinery Division of ASAE in January 2003.

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  ISSN 0883–8542

PROCEDURE

Investment, repair, maintenance, fuel, lubrication, taxes, insurance, and housing contribute to the total cost of a tractor (labor not included). Standard relationships (*ASAE Standards*, 2002a, 2002b) and amortization formulas were used to estimate these costs with tractor price estimated as a function of tractor power rating.

Tractor prices were obtained from dealerships for three tractor brands (Case–IH, Deere, and New Holland). Price data were collected for 24 diesel–powered, fixed–frame (non–articulating) wheeled tractors ranging from 30 to 205 kW (40 to 275 hp). Salespersons were asked to select the most common features typically chosen for a particular tractor size; these were options such as tire size, additional ballast, and the number of hydraulic remote outlets. For all brands, cabs were included on tractors over 67 kW (90 hp) and MFWD was included on tractors over 75 kW (100 hp). All prices were list prices effective in January 2002. The data are illustrated in figure 1 along with the resulting price function that was:

$$LP_{\$} = -1.37(P_{kW})^2 + 1250(P_{kW}) - 20500 \quad (r^2 = 0.98) \quad (1)$$

where

$LP_{\$}$ = list price ($)

P_{kW} = tractor rated PTO power (kW)

The length of time to keep the tractor (N_y) and annual usage ($H_{h/y}$) are inputs that affect salvage value (trade–in) and repair and maintenance costs. Remaining value was estimated from functions in *ASAE Standards* (2002a). The investment was amortized over time with inputs of N_y and annual interest rate (i, decimal/y). An equivalent annual cost was computed using annuity formulas.

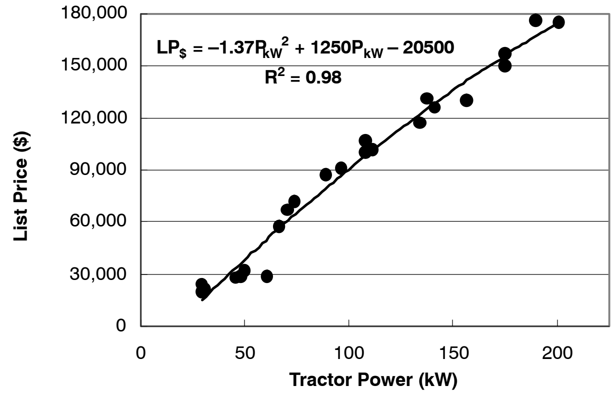

Figure 1. Tractor list price vs. tractor rated power.

Cumulative repair and maintenance costs were estimated from relationships in *ASAE Standards* that are based on repair factors and cumulative use (*ASAE Standards*, 2002a). The uneven stream of repair and maintenance expenses was converted to an equivalent annuity for the term, N_y, based on the interest rate.

Typical fuel and lubrication oil consumption rates were also estimated for diesel powered tractors from standard relationships (*ASAE Standards*, 2002b). Fuel and lubrication costs were proportional to use and based on an input of fuel price ($P_{f,\$/L}$); lubricant price was assumed to be four times as much as fuel price. Other assumptions in the analysis included zero inflation and taxes, insurance, and housing (collectively) were 2% of purchase price per year.

Abbrev.	*Detailed description*	*Scenario 1*	*Scenario 2*	*Units*	*Documentation notes*
Inputs					
Pkw	tractor power	75	75	kW	
Ny	length of time to keep the tractor	5	7	years	
H	use of tractor each year	500	500	hours	
i	interest or discount rate	0.080	0.080	decimal/y	
Pf	price of fuel	0.32	0.32	$/l	
TIH	taxes, insurance, and housing	0.02	0.02	fraction of purchase price/y	
Intermediate					
LP	list purchase price of tractor	65094	65094	$	function fit to current price data
RV	remaining value of tractor at end of period	49.1	43.5	%	ASAE D 497 function
SV	salvage value in Ny years	31942	28315	$	RV/100*LP
PV	present value of price less SV	43355	48573	$, today	LP-SV/(1+i)^Ny
RM	repair & maintenance cost	616	1253	$, today	sum from cumulative table (not shown)
F	average fuel consumption	16.60	16.60	l/h	ASAE D 497 function
L	lubrication consumption	0.066	0.066	l/h	ASAE D 497 function
FC	fuel cost	2632	2632	$/y	F*H*Pf
PL	price of lubricant	1.27	1.27	$/l	4*Pf, assumed
LC	lubricant cost	42	42	$/y	L*H*PL
TIH2	taxes, insurance, and housing	1302	1302	$/y	TIH*LP
Output					
AC	cost for the tractor, without fuel & lube	12,315	10,872	$/y	PMT(i,Ny,-PV-RM)+TIH2
FLC	fuel and lubricant cost	2,673	2,673	$/y	FC+LC
HCtot	hourly cost for the tractor	29.98	27.09	$/hour	(AC+FLC)/H
HCnf	hourly cost for the tractor, no fuel & lube	24.63	21.74	$/hour	AC/H
SCtot	**specific cost for tractor power**	**0.402**	**0.363**	**$/kWh**	**HCtot/PkW**
SCnf	**specific cost for tractor power, no fuel & lube**	**0.330**	**0.292**	**$/kWh**	**HCnf/PkW**
SCtot2	specific cost for tractor power -- model	0.397	0.348	$/kWh	176*Pkw^0.109*Ny^-0.392*H^-0.848*i^0.22*Pf^0.094
SCnf2	specific cost for tractor power -- model, no fuel & lub	0.326	0.282	$/kWh	278*Pkw^0.122*Ny^-0.437*H^-0.958*i^0.244

Figure 2. Spreadsheet layout of tractor benchmarking computations (repair and maintenance estimation section not shown; available at www.abe.psu.edu/fac/Buckmaster/publ/tractorcost.xls).

Figure 2 illustrates a spreadsheet implementation (as well as the complete equations) to compute costs for different scenarios in a side–by–side comparison. With replacement of the list price function with a known value, a user could very closely project owning and operating costs for a particular tractor.

As a step toward providing a simple function useful in other machinery cost models, specific tractor cost projections were computed in a factorial manner with the inputs varied as follows:

- P_{kW} from 37.3 to 224 kW in increments of 37.3 kW (50 to 300 hp, by 50 hp) – 6 values (note this requires a slight extrapolation of the $LP_{\$}$ function which was based on tractors up to 205 kW)
- $H_{h/y}$ from 200 to 600 h/y in increments of 200 h/y – 3 values
- $P_{f,\$/L}$ from \$0.211 to \$0.422/L in increments of \$0.106/L (\$0.80 to \$1.60/gal, by \$0.40/gal) – 3 values
- N_y from 2 to 10 y in increments of 4 y – 3 values
- $i_{decimal/y}$ from 0.03 to 0.11 in increments of .04 (3 to 11%) – 3 values

This factorial replication resulted in a total of 486 sets of inputs for which specific tractor cost (\$/kWh) without fuel and lubrication included ($SC_{nofuel, \$/kWh}$) and specific tractor cost with fuel and lubrication and fuel included ($SC_{total, \$/kWh}$) were estimated. These cost projections were estimates of tractor costs since they were based on empirical models and interest formulas.

Based on the principles involved, increases in $LP_{\$}$, $i_{decimal/y}$, and $P_{f,\$/L}$ all lead to higher tractor cost. Conversely, increases in N_y and $H_{h/y}$ (within a range), lead to lower tractor costs. Based on this and simple scatter plots of the cost projections, empirical functions were generated to estimate specific cost as a product of each input raised to an exponent. The functions were generated using nonlinear regression – minimizing the sum of squares of error in the non–linear empirical functions by changing the parameter estimates (the leading coefficient and exponents).

Results and Discussion

The results of nonlinear regression on the cost projections (486 sets of inputs) generated using relationships in figure 2 were:

$$SC_{nofuel, \$/kWh} = 278\ P_{kW}^{0.122}\ N_y^{-0.437}\ H_{h/y}^{-0.958}\ i_{decimal/y}^{0.244}\ (R^2 = 0.888) \quad (2)$$

$$SC_{total, \$/kWh} = 176\ P_{kW}^{0.109}\ N_y^{-0.392}\ H_{h/y}^{-0.848}\ i_{decimal/y}^{0.220}\ P_{f,\$/L}^{0.094}\ (R^2 = 0.824) \quad (3)$$

where

SC = specific tractor cost (\$/kWh)
P_{kW} = tractor power (37.3 to 224 kW)
$H_{h/y}$ = use of the tractor each year (200 to 600 h/y)
$P_{f,\$/L}$ = price of fuel (\$0.211 to \$0.422/L)
N_y = length of time to keep the tractor (2 to 10 y)
$i_{decimal/y}$ = interest or discount rate [0.03 to 0.11/y (3 to 11%/y)]

The fit of these empirical functions to the cost projections is illustrated in figures 3 and 4. For $SC_{total, \$/kWh}$, the average error was \$0.00074/kWh or 0.12%. Confidence bands on the errors suggest that, 90% of the time, the empirical predictions were in error by less than \$0.0045/kWh or 0.75%. For the total specific tractor cost, the largest error between a cost projection and the corresponding result of the exponential function was \$0.12/kWh or 20%. The differences between the exponential function estimates and cost projections were smaller when specific cost was low (figs. 3 and 4).

For $SC_{nofuel, \$/kWh}$, the average error was \$0.00038/kWh or 0.80%. Confidence bands suggest that 90% of the time the empirical predictions were in error by less than \$0.0040/kWh or 1.5%. For the specific tractor cost without fuel and lubrication included, the empirical function was always within \$0.08/kWh and at most was 20% off of the cost projections used to fit the exponential functions.

As one example, these relationships suggest the cost for a 75–kW tractor kept for 5 y, used 500 h/y with an annual interest rate of 8% and fuel cost of \$0.32/L would be \$0.326/kWh without fuel and lubrication and \$0.397/kWh total (fig. 2). Estimates such as this can help farmers and custom operators estimate tractor expenses, evaluate lease/

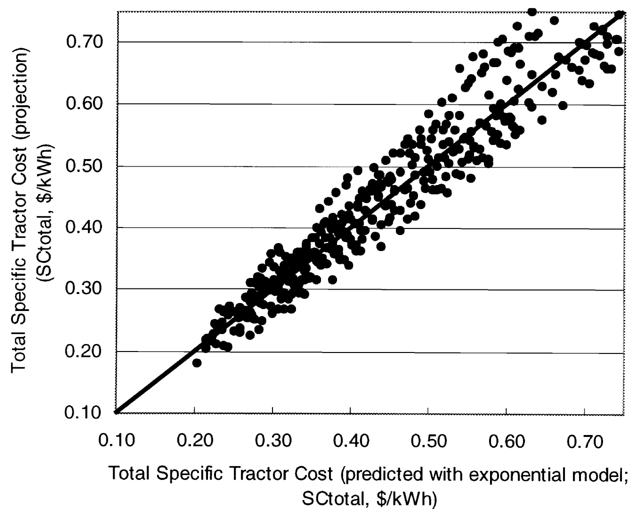

Figure 3. Fit of the empirical function for specific tractor cost with fuel included.

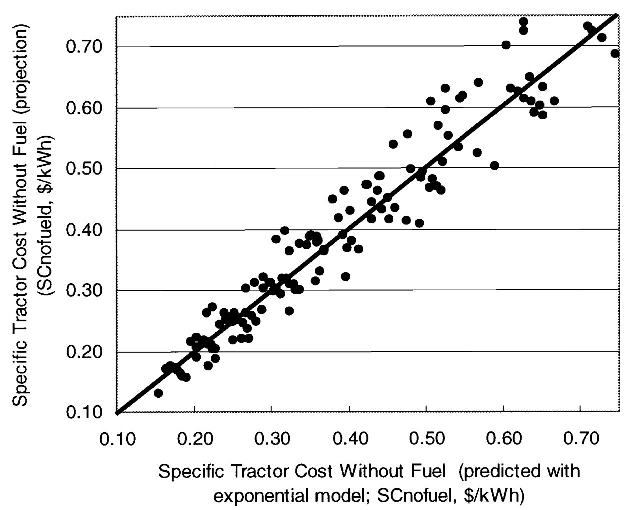

Figure 4. Fit of the empirical function for specific tractor cost without fuel included.

rent/buy options, and compare tractor purchase options. Dealers should not use these relationships to set prices for profit targets, but could use them to determine competitiveness of their selling prices and lease rates. Manufacturers could use these benchmark relationships to determine competitiveness and facilitate customer education. For this example, approximately $24/h ($0.326/kWh•75 kW) is a benchmark for comparison of rental or lease rates. For computing tractor operating costs or custom rates, $30/h ($0.397/kWh•75kW) is a reasonable benchmark (without labor) in this case.

Because these relationships do not include factors relating to tax implications or obsolescence, they are not useful to pinpoint the optimal replacement age for tractors. Nor can they be used to evaluate used power units. They are not directly applicable to self–propelled equipment, but a similar process could be followed to generate comparable functions for self–propelled harvesters or transport units. These relationships do not include added value from advanced technologies (such as slip control, engine/transmission management systems, GPS and CAN integration with implements), but as benchmarks for tractors without such devices, the marginal cost of adding these technologies can be more easily identified.

CONCLUSIONS

Standard relationships for costs of owning and operating tractors were integrated to compute benchmark specific tractor cost ($/kWh). These benchmark costs may be valuable in assessing competitiveness of rates for rental, leasing, or custom operations. The empirical functions for specific tractor cost (with fuel, or without) were within 1.5% of directly computed estimates 90% of the time.

AUTHOR COMMENTARY

This article grew out of a class exercise in an Agricultural Systems Management course titled "Selection and Management of Agricultural Machinery." The exercise taught or reinforced several principles to the students including: curve fitting and regression, marginal cost of power, time value of money, models for cost estimates, machinery economics, value of ASAE Standards and data, logical spread sheeting, and the whole equals the sum of the parts (a systems approach).

MODEL AVAILABILITY

A Microsoft Excel workbook containing spreadsheet implementations of figure 1 in both SI units (kW, L) and English units (hp, gal) is available on the Internet at www.abe.psu.edu/fac/Buckmaster/publ/tractorcost.xls.

REFERENCES

ASAE Standards. 2002a. D497.4. Agricultural machinery management data. St. Joseph, Mich.: ASAE.

_____. 2002b. EP496.2. Agricultural machinery management. St. Joseph, Mich.: ASAE.

Lavoie, G., K. Gunjal, and G.S.V. Raghavan. 1991. Soil compaction, machinery selection, and optimum crop planning. *Transactions of the ASAE* 34(1): 2–8.

McClendon, R. W., M. E. Wetzstein, D. M. Edwards, and L. H. Chen. 1987. Risk efficiency of machinery selection for double cropping via simulation. *Transactions of the ASAE* 30(5): 1259–1265

Parmar, R. S., R. W. McClendon, and W. D. Potter. 1996. Farm machinery selection using simulation and genetic algorithms. *Transactions of the ASAE* 39(5): 1905–1909

Rotz, C. A., H. A. Muhtar, and J. R. Black. 1983. A multiple crop machinery selection algorithm. *Transactions of the ASAE* 26(6): 1644–1649

Siemens, J., K. Hamburg, and T. Tyrrell. 1990. A farm machinery selection and management program. *J. Prod. Agr.* 3(2): 212–219.