ABSTRACT
Construction equipment managers are tasked with developing accurate hourly charges for the
machines in their fleet by controlling their owning and operating costs. These two categories of
costs are composed of several elements that differ from each other in terms of how they behave
over time, whether they depend on how intensely the machine is used, whether they are fixed or
variable, and – most importantly – how predictable they are. The residual value has been the
least well known and most difficult to predict among these elements. It can provide a significant
cash inflow upon selling of the machine at the end of its economic life.

Good recordkeeping is the start of all managerial decision making. Own historical cost data
are the most precious resource from which equipment managers can derive solid estimates for
the residual value. Published auction records follow suit and may provide a large amount of
usable data points to forecast the residual value of heavy construction equipment for a particular
make and model. This paper describes how such data types can be turned into information based
on a statistically proven yet easy-to-follow methodology. Residual value grids are introduced as
an intuitive way to present the analysis graphically.

1 INTRODUCTION

Equipment economics is the art and science of managing the financial dimension of construction
equipment. The key questions that the equipment manager needs to answer are all related to
keeping at a minimum the costs of owning and operating a machine over a certain period of time
to ensure the profitability of the company. They include the decision whether a piece of
equipment should be bought, leased, or rented and what prices are acceptable, selecting financing
from available loan options if necessary, assessing how much it is worth at any given point in
time, and determining the optimum duration of owning the equipment, i.e., the economic life
(Vorster 2004b).

Not only are the costs composed of various elements that each exhibit a distinctly
different behavior over time, the value of money itself changes with time due to inflation.

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Managing construction equipment financially can thus appear to be a daunting task. In this paper the authors present a methodology for forecasting the least known element of the cost calculation, the residual value. The following sections present the residual value as a part of the owning costs, give its definition, and report on the current state of knowledge. Furthermore, the data that can be used to forecast the residual value are introduced, important issues are discussed for correctly preparing and using them in fitting a curve, and the graphical representation with residual value grids that visualizes the statistical analysis is explained.

2 OWNING AND OPERATING COST

The costs for individual pieces of equipment are distinguished into the two categories of owning and operating costs. Owning costs are connected to having ownership of a machine and accrue regardless of whether it is actually utilized on a construction project or not. They typically comprise the following elements (Lucko and Vorster 2003): The initial purchase price adjusted for any dealer discounts and trade-in values plus all fees associated with obtaining the machine as applicable, e.g., license, title, delivery, and setup is a major cash outflow. Additionally, payments for the interest and principal of the loan from financing the machine, insurance premiums, and property taxes need to be covered, the latter ones of which may depend on the age of the machine. These cash outflows are offset by the residual value, which provides a cash inflow from selling the machine in the market at the end of the owning period.

Operating costs, on the other hand, are only incurred when the machine is working on an earthmoving job and are directly dependent on the hours of use. They include all consumables, (fuel, oil, and grease), and wear items in the traction system (tires or tracks) and attachments of the machine (replaceable parts, e.g., a scraper cutting edge or excavator bucket teeth), labor and parts costs from preventive maintenance and unscheduled repairs (Mitchell 1998), ranging from minor routine items to major rebuilds, e.g., of the undercarriage, and finally the wages and fringe benefits for the operator (Lucko and Vorster 2003).

The remaining balance of owning and operating costs plus the desired profit margin has to be recovered entirely by operating the machine in the field to generate revenues and achieve a positive bottom line. Equipment managers therefore need to carefully control each cost element and their sum over the duration of the owning period in comparison with the hourly rate that is charged for using the machine. However, the owning and operating cost elements differ from each other with respect to how easy they are to predict. The purchase price and associated fees for the machine are known and have already occurred. Interest and principal payments from financing it can be calculated with time-value-of-money formulas. The insurance premiums may decline with age based on the assessed value of the machine for tax purposes that is calculated with a known depreciation model. “The true residual value of a machine when sold at any point in its life is an unknown that depends on many factors” (Vorster 2004a, p64).

Major factors related to the machine itself that influence its residual value are the type, make, and model of the machine, its age in calendar years, its condition rating, including the condition of its engine, body, and undercarriage as well as the type, size, and condition of wear items, i.e., its tires or tracks and attachments, and whether its setup includes the most current technology (Grinyer 1973). External factor such as the overall state of the economy in which the machine is sold and the particular region with its local contractors, volume of construction work, climate, and soils conditions may all further influence the residual value. In current industry practice the age is closely linked with its cumulative hours of use by equipment managers.
typically assuming a value of about 1500 to 2000 hours of average annual use in cost calculations. However, research on the extent of the correlation between these two measures and on the reliability of hour meters still needs to be conducted, as Vorster (2004a, p65) notes: “Auction companies wisely stay clear of publishing hours worked due to the fact that it is difficult to confirm the data with confidence.” Hour meters record when the engine is running but do not distinguish whether a machine is working productively or sitting idle. For agricultural equipment, Perry and Glyer (1990, p524) notes that considering “the importance and the amount of research conducted on depreciation, no clear consensus exists about the depreciation patterns followed by different types of capital goods.”

Operating costs all depend on the hours of use. The cost of consumables and wear items can typically be forecasted based on historical cost records that companies maintain. Future values may need to be corrected for the effect of inflation.

2.1 Residual Value Definition

Residual value can be “defined as the price for which a piece of used equipment could be sold in the market at a particular time” in a fair transaction between and equally informed buyer and seller. It is the value that remains after losses “related to the equipment itself (physical condition, age, deterioration or obsolescence) or the economic situation (supply and demand for the equipment or its product)” have been considered. The literature knows the concept of residual value, which is the term that is used in this paper, under a variety of similar names, including “resale value, remaining value, recovery value, salvage value, scrap value, terminal value, trade-in value, and fair market value” (Lucko and Vorster 2003, p3). Its importance for owning and operation cost calculations has been highlighted in numerous econometric publications (Perry and Glyer 1990, Cross and Perry 1995, Cross and Perry 1996, Unterschultz and Mumey 1996)

Note that all of this terminology refers to a concept that is fundamentally different from depreciation (Lucko 2003, p5), which originated in cost accounting as “the process of determining the book value of an asset for administrative and taxation purposes by regularly charging expenses to the initial capital investment” based on a prescribed model. Common depreciation methods that estimate such loss of assessed value are straight line, declining balance, units-of-production, and sump-of-the-years depreciations that are applied to a particular useful life. None of these models, however, consider any actual data about the machine or the economic circumstances under which it is sold. They all depreciate to a zero book value and are used for the purpose of “minimizing the tax liability of the company as permissible under the currently governing tax legislation” (Lucko 2003, p26) and not for minimizing the hourly owning and operating cost or determining the economic life of the machine. The residual value is realized in the marketplace through actual transactions, i.e., “evidences of value” (Cowles and Elfar 1978, p141), whereas a depreciated value remains an artificial estimate (Vorster 2003b).

2.2 Current Application

Numerous examples of owning and operating cost calculations show that the industry practice for including the residual value takes two forms. Typically, “many owners prefer to depreciate their equipment to zero value” (Caterpillar Performance Handbook 2001, p22-10) and implicitly assume that it has no value at the end of its economic life. However, this simplifying assumption can be considered overly conservative (Grinyer 1973), since “even a completely dysfunctional
piece of equipment will have some value as scrap metal” (Lucko 2003, p25). Therefore, the Caterpillar Performance Handbook (2001) and the Deere Performance Handbook (2002) urge that a non-zero residual value be considered in the calculations that should be derived from the experience of the equipment owner. The second common approach is to assume a monetary value that commonly is expressed either as a multiple of $10,000 (Sears and Clough 1981) or as a fixed percentage of the purchase price in 5% to 10% steps depending on age (Corps of Engineers 2001, p2-4). Equipment managers use rules-of-thumb (Cubbage et al. 1991) that comprise a single even percentage of the initial value for completely different equipment types, makes, and models, as conversations with professionals revealed. They may make slight adjustments to their estimate based on their intuition, e.g., for unusual types, setups, or utilization (Lucko et al. 2007), notwithstanding these typically are not based on documented corporate experience.

Such approaches strongly simplify what may in fact be a more complex combination of factors that influence the residual value for a particular machine, as has been explained in the previous section, do not make beneficial use of existing data, lack a coherent underlying mathematical model, and accordingly do not offer any verifiable forecasting capability (Lucko 2003). Briefly stated, they assume a single isolated point on the curve of residual value over time and ignore any potential variability. The criticality of enhancing this current state of knowledge is underlined by a recent study that conducted a sensitivity analysis for the impact of residual value on equipment cost calculations and found it to contribute in a statistically significant amount to all examined realistic scenarios (Lucko et al. 2007).

3 DATA FOR RESIDUAL VALUE FORECASTS

The basic principle holds that the more data points are available for developing an economic forecast, the more accurate the forecast will be overall. Larger sample sizes will improve the power of hypothesis tests (Hicks and Turner 1999) and thus the confidence that users can have in their predictions. On the other hand, the more specific the forecast shall be for a particular piece of equipment, the more difficult it becomes to collect a large enough number of data that all reflect transactions under the very same circumstances. (Vorster 2004a). It is therefore necessary to develop a healthy balance between the needed level of detail of the forecast and the number and nature of the available data.

The scientific literature gives some guidelines how large datasets should be at least to yield results of acceptable precision. The number of complete observations, i.e., number of data points $n$, each being one sale of a machine with the associated type, make, model, date, age, and price is recommended to be $n \geq 15 \cdot k$ for multiple linear regression (Stevens 1995), where $k$ is the number of explanatory variables, i.e., factors that are built into the statistical model. Another recommendation is $n \geq 50 + 8 \cdot k$ for analyzing multiple correlation and $n \geq 104 + k$ for testing explanatory variables (Green 1991).

3.1 Maintaining Databases

Clearly, the best possible data come from the own company’s records. Any piece of equipment that has ever been bought, operated, and sold in the past has not only a productive asset to the company but is also a goldmine of data that can be used to gauge future business decisions. The company should follow a standardized format to record owning and operating cost elements for
each machine in their fleet in a database. Due to the different nature of owning costs versus operating costs, it is recommended to keep the expenses and revenues clearly separated for these two categories. Such cost control system will allow tracking cost changes to their source – whether they are related to managerial decisions in the finance and accounting department or whether they are related to operational issues of “running a shop, operator training, preventive maintenance, repairs and rebuilds” (Vorster 2003a, p63). Note, however, “that the two elements of total costs are very dependent on each other. Selecting premium equipment will push owning costs up and lower operating costs. Rebuilds will push operating cost up, but extend life and lower owning costs. Allowing our fleet to age lowers owning costs but increases operating costs.” Any decision of the equipment managers needs to be mindful of these interdependencies.

3.2 Auction Records

Unless a large fleet is owned and operated that would yield a sufficient number of data points, the data that can be extracted from auction sales records (Koger and Dubois 1999) are the best source from which a realistic model for the residual value can be developed. Several commercial publishers collect auction data for construction equipment through representatives that attend equipment auctions and make them available for a subscription fee, including Last Bid™ and Top Bid. These sources contain a large selection of equipment types, makes, and models along with their serial number, year of manufacture, a brief verbal description, condition rating as “a proxy for the compound of all physical influences on the machine, i.e., wear and tear as well as maintenance and repair” (Lucko et al. 2006, p724), auction firm, location, date, and price. Meter hours or mileage is not reported for various reasons, as mentioned above.

The auction data should be augmented by equipment parameters that allow developing size categories to describe the machines more closely, e.g., by bucket volume for excavators or horse power for dozers. Such parameters are found in performance handbooks that are published by the equipment manufacturers, in their specification summary sheets, product line documents, and in the Green Guide™. Finally list prices are found in price lists from manufacturers and their distributors and in the Green Guide™, including the costs for non-standard options. Any external records, whether auction prices or list prices, should be reviewed for correctness and consistency. Incomplete entries should not be used in the analysis. Equipment age in calendar years is calculated by taking the difference between the auction date and the year of manufacture.

Developing a statistical model can take either of two approaches. First, the dataset can include a number of different factors for each data point, which together create the coefficients of the statistical model, as carried out in a recent major study of equipment cost and residual value (Lucko 2003). For using the model the user then needs to select the particular constellation of these factors that applies to the machine of interest. Or second, the dataset can be filtered to include only machines of same category as the machine of interest (e.g., from the same region or of the same condition) so that the model itself will be simpler and easier to handle, albeit not applicable to any other categories (Vorster 2004a). Companies interested in the residual value for individual machines may find this approach much more expedient and less time-intensive.

4 STATISTICAL CONSIDERATIONS

Making accurate forecasts of the residual value requires that its behavior and dependency on various factors is extracted from real-world data. The following sections briefly review a number
of important considerations that an equipment manager needs to address when determining how much a used piece of heavy construction equipment is worth.

4.1 List Prices versus Actual Transactions

Most manufacturers publish manufacturers suggested retail prices (MSRP), or list prices, for their products. While list prices are readily available and widely advertised, they should be treated with caution for the purpose of predicting the residual value, as they do not reflect any actual sales that occurred between a buyer and a seller, but rather a recommendation with what offering price the seller, i.e., the distributor in the case of construction equipment, should start the negotiations. Moreover, construction equipment is typically sold at discounts off the MSRP, whose details depend on the particular business relationship between distributors and equipment owners and thus can be considered proprietary information.

List prices, however, can serve well as baselines for calculating residual value percentages (Cross and Perry 1995). If a company has carefully maintained a database of their actual purchase and sales prices for all machines that it owned and operated in the past, it should certainly use these data to the fullest extent, which are the best reflection of the circumstances under which that particular company has been operating. In general, records from past market transactions are much more suitable than list prices to determine the residual value (Unterschultz and Mumey 1996), which should be a representation of what a machine can actually be sold for in the market. Simply said, a price offer only becomes an economic value once another party has been found that is willing to pay it.

4.2 Inflation Adjustment

Since the purchase and sale of machines occur at different points in time that typically occur several years apart, inflation may change the monetary value during this time span. It is therefore necessary to correct all cost values in the database to a common base year, which removes the effect of inflation. Only auction prices and list prices that have been inflation-correct may be combined into residual value percent or may be used together in the same owning and operating cost calculation.

Measures of inflation for various industry applications are published by the Bureau of Labor Statistics (BLS), an agency of the U.S. Department of Labor. More macroeconomic data are available from the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce. Note that the producer price index (PPI) that is reported monthly by BLS comes in various forms; the research study on which this paper is based (Lucko 2003) used the widely accepted PPI for finished manufacturer goods. Cross and Perry (1995, 1996) have successfully used it to adjust residual values for inflation. Mitchell (1998) created an inflation index of weighted macroeconomic indicators to adjust equipment repair costs. Lucko (2003) developed an average annual PPI from the monthly PPI values based on Kastens (1997). All values need to be corrected with the same type of inflation index for consistency of the dataset.

4.3 Normalization for Comparisons

In practice, the residual value is expressed in dollars, just as the list price or the initial purchase price. It may, however, the useful to normalize the residual value by dividing its dollar value by
the list price (Cross and Perry 1995). Only this normalization to residual value percent allows that different types, makes, and models can be directly compared with each other (Cubbage et al. 1991, Reid and Bradford 1983, Perry et al. 1990, Cross and Perry 1996). Normalization means a small change in the amount of information that is contained in a dataset, where the previous residual value and list price are replaced by a single value residual value percent, which in turn causes small changes in statistical parameters, e.g. the mean square error that describe the dataset (Lucko et al. 2006). This extent of this effect is typically negligible.

4.4 Outliers

It is strongly recommended that the dataset be plotted in a diagram to identify any patterns before the analysis is performed. In particular, showing the relationship of residual value over age graphically in a so-called scatterplot will make identifying any unusual data points easy. They are called outliers in the statistical literature and are defined as “extreme observations that are inconsistent with the basic relationship captured by a dataset” for “differing significantly in sign or magnitude from other data points” (Lucko et al. 2006, p727). Closer investigation of the database could reveal whether they should still be considered valid entries or whether they were caused by “errors in measuring or recording” and should be purged.

In a full statistical analysis, outliers among the data points would be identified and eliminated by building a tentative regression model that attempts a “best fit” smooth curve, which is shaped such that its average distance to all data points is minimized, calculating the actual distances between each point and the curve, called residuals in the statistical literature (Montgomery et al. 2001), and scrutinizing all points that are located beyond a chosen distance from the curve. After removal of the outliers the final coefficients of the same regression model would be determined. Several different types of residuals exist, e.g. studentized residuals that were used by Lucko (2003). For practical purposes, tracking the quality and accuracy of each entry into the company database and closely examining data points that appear deviant from the bulk in the diagram is a workable approach.

4.5 Regression Analysis

A common statistical approach of modeling data is modeling them using simple linear regression (SLR) analysis or multiple linear regression (MLR) analysis. Simple and multiple in this context mean that either one or several explanatory variables, i.e., influential factors, are included in the model to forecast the value of interest, in this case the residual value. Linear regression means that the individual terms in the regression equation are additive; they certainly individually can be of higher order and more complex with respect to the coefficients and variables that they contain to replicate the behavior of the dataset (Lucko 2003). Mitchell (1998) used MLR in research on repair costs and Lucko (2003) used MLR in research on the residual value itself. Non-linear regression (NLR) models are theoretically more powerful than SLR and MLR but are very difficult to solve and have not been found necessary to be used for equipment cost calculations.

In a typical regression analysis, various different models are created and tested for best fit with the data once their coefficients have been determined. Measures of the goodness-of-fit are the so-called coefficient of determination $R^2$, which describes how much variability in the data is captured by the model as opposed to how much remains unexplained, the adjusted coefficient of
determination $R^2_{\text{adjusted}}$, which includes a correction that makes it independent of the actual sample size and resistant to including unnecessary extra factors in the model, and the mean square error, which is a direct measure of how far away the data are from the curve. Large coefficients of determination and small mean square errors indicate good fits. Once the statistical model has thus been prepared, it can be used to forecast new residual values by setting its variables to the constellation of factors that describes the machine whose residual value is sought. Commercial spreadsheet software can fit so-called trend-lines to datasets, which requires that the data points have already been graphed in a 2D chart. The software performs a standard SLR analysis using a linear, polynomial, logarithmic, power, or exponential function, or a moving average model, displays the coefficients, and calculates the coefficient of determination. An add-in for the software extends its capabilities to MLR analysis.

Newer data points for additional equipment sales should be added to the database as soon as they become available, whether from own equipment transactions or from auctions, and the statistical analysis should be re-run with the same basic model to keep its forecasting capabilities up to date with fine-tuned coefficients. In the long run, forecasting the residual value could thus become an ongoing endeavor (Cubbage et al. 1991) that always includes the latest market data to give equipment managers the most current tool to support their decision making.

Regression analysis makes several general assumptions on the nature of the relationship between the explanatory variables and the forecasted result and on the randomness of the error terms that remain outside of the best fitted model (Montgomery et al. 2001). Examining a large datasets for 28 different common types and size classes of heavy construction equipment found that these assumptions overall were satisfied by all examined datasets (Lucko 2003). The equipment age was consistently found to be the most influential factor for residual value.

4.6 Functional Form

The statistical model that was ultimately chosen based on the coefficient of determination after examining several polynomial, exponential, and logarithmic MLR models was a second-order polynomial function of equipment age in calendar years with added terms for manufacturer, condition, and regions – all of which were modeled with sets of binary indicator variables – and in some versions also macroeconomic measures. The stability and consistency of the regression model was validated by various hypothesis tests in an internal random cross-validation procedure. Coefficients were validated by their sign and magnitude and were found to support the initial assumption on the behavior of the residual value. Assessing the quality of a statistical prediction needs to consider two important pieces of information. The actual forecasted value is given by the mean of the data points. Additionally, however, the variability of the data points around the best fit curve that represents said mean plays an important role. Confidence and prediction intervals describe the limits within which one would expect the true residual value and any future observations to fall, respectively. Their standard formulas for these two intervals were slightly modified to accommodate the MLR nature of the model and their width was found to be satisfactorily narrow for the examined datasets of different equipment types and sizes.

Table 1 shows the basic functional expressions for residual value percent (RVP) that were derived for five classes of common equipment types and sizes: Track excavators, wheel loaders, backhoe loaders, articulated trucks, and track dozers. The coefficients $m_1$, $m_2$, $m_3$, and $c_1$, $c_2$, and $c_3$, and $r_1$, $r_2$, $r_3$ are triplets of binary indicator variables encoding the manufacturer, condition rating, and regions, respectively, since these verbal descriptions needed to be
converted to numeric format to be usable in the regression analysis (Lucko et al. 2006). For more details on the use of this statistical model the reader is referred to the original study (Lucko 2003).

Table 1: Regression Equations for Common Equipment Types and Sizes

<table>
<thead>
<tr>
<th>Type</th>
<th>Size</th>
<th>Equation</th>
<th>Data</th>
<th>$R^2$</th>
<th>$R^2_{adjusted}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track excavators</td>
<td>25,000-50,000 lbs standard operating weight</td>
<td>$RVP = 0.59899 + 0.00201 \cdot \text{age}^2 - 0.05154 \cdot \text{age} + 0.0 \cdot m_1 - 0.07731 \cdot m_2 - 0.04378 \cdot m_3 + 0.02271 \cdot c_1 - 0.01197 \cdot c_2 + 0.01249 \cdot c_3 - 0.03289 \cdot r_1 - 0.00638 \cdot r_2 - 0.00266 \cdot r_3$</td>
<td>1,888</td>
<td>0.7276</td>
<td>0.7246</td>
</tr>
<tr>
<td>Wheel loaders</td>
<td>2-4 cy general purpose bucket size</td>
<td>$RVP = 0.73678 + 0.00243 \cdot \text{age}^2 - 0.06494 \cdot \text{age} - 0.13094 \cdot m_1 - 0.09149 \cdot m_2 - 0.08869 \cdot m_3 + 0.02927 \cdot c_1 - 0.02013 \cdot c_2 + 0.02033 \cdot c_3 + 0.00681 \cdot r_1 + 0.00816 \cdot r_2 + 0.02213 \cdot r_3$</td>
<td>3,857</td>
<td>0.7473</td>
<td>0.7459</td>
</tr>
<tr>
<td>Backhoe loaders</td>
<td>&gt; 1 cy general purpose bucket size (of backhoe)</td>
<td>$RVP = 0.76828 + 0.00247 \cdot \text{age}^2 - 0.06437 \cdot \text{age} + 0.0 \cdot m_1 - 0.14843 \cdot m_2 - 0.14246 \cdot m_3 + 0.04734 \cdot c_1 - 0.02229 \cdot c_2 + 0.02465 \cdot c_3 - 0.02278 \cdot r_1 - 0.00867 \cdot r_2 + 0.03171 \cdot r_3$</td>
<td>7,530</td>
<td>0.6965</td>
<td>0.6957</td>
</tr>
<tr>
<td>Articulated trucks</td>
<td>0-50,000 lbs standard operating weight (empty)</td>
<td>$RVP = 0.53409 + 0.00289 \cdot \text{age}^2 - 0.06904 \cdot \text{age} + 0.06272 \cdot m_1 - 0.03535 \cdot m_2 + 0.0 \cdot m_3 + 0.02996 \cdot c_1 - 0.02999 \cdot m_2 + 0.03019 \cdot m_3 + 0.00632 \cdot r_1 + 0.01014 \cdot r_2 + 0.01387 \cdot r_3$</td>
<td>1,658</td>
<td>0.6765</td>
<td>0.6726</td>
</tr>
<tr>
<td>Track dozers</td>
<td>100-200 HP (net flywheel)</td>
<td>$RVP = 0.66202 + 0.0031 \cdot \text{age}^2 - 0.07476 \cdot \text{age} + 0.0 \cdot m_1 - 0.10034 \cdot m_2 - 0.02558 \cdot m_3 + 0.04668 \cdot c_1 - 0.02164 \cdot c_2 + 0.01716 \cdot c_3 + 0.02785 \cdot r_1 + 0.01804 \cdot r_2 + 0.02694 \cdot r_3$</td>
<td>4,594</td>
<td>0.8056</td>
<td>0.8047</td>
</tr>
</tbody>
</table>

5 RESIDUAL VALUE GRIDS

The practical implementation of the statistical analysis method as described in the previous section has proven to be rather time-consuming and demands a considerable working knowledge of statistical methods and testing from the user. At the same time, the regression equation and the scatterplot diagram shown in Figure 1, which shows each data point by a small mark at its respective coordinates, soon becomes unclear for datasets as large as the examined ones. Even small marks become almost indistinguishable for the 15 different ages, other than tracing the familiar behavior of residual value over age, which “slopes downward and outward with an ever-decreasing gradient” with growing age (Vorster 2006, p71). In particular, part of the information contained in the dataset – how many pieces of equipment of each age group were sold and yielded what residual value – is contained in the regression equation but is not visible to the user anymore. This information, however, may be important to evaluate the accuracy of a forecast, especially for smaller datasets. Therefore, an innovative extension of histograms is introduced for being used in forecasting residual values.

5.1 Histograms

Histograms present large amounts of data points in aggregated form in a clear diagram. Two steps are necessary for preparing a histogram. First, the entire range across which the data are spanning is divided into a suitable number of categories of equal width. Second, the numbers of
data points that fall within each category are counted. These values are plotted as vertical bars in the diagram, one per category, whose heights are proportional to the number of data points.

5.2 Residual Value Grids

Residual value grids are 3D histograms that present the age of the machine in years and the residual value in inflation-corrected dollars or as a percentage of the MSRP along with the number of observations for each category of age and residual value. Since the two measures, age and residual value, are already plotted in a 2D diagram such as in Figure 1, the count of data points would necessarily need to grow into the third dimension and create a stepped surface. Instead, the residual value grids use a cartographic display technique that combines smoothened lines of equal height above ground, isohypses, with colors that change their shade and intensity with changes in count. Individual columns have been fused into contours. The residual value grid thus is comparable to the bird’s eye view of a terrain map that charts the topography of a landscape with its valleys and ridges. Contour plots have already been used by Lucko et al. (2006) to visualize the hourly owning and operating costs of construction equipment. In this paper, the residual value has been singled out as the most elusive element of these owning and operating costs. Its behavior is now shown in the intuitive graphical form of residual value grids.

Spreadsheet software allows its users to create simple 2D histograms automatically using the counting (frequency) function for individual ranges within the sorted data. The 2D histogram itself is a so-called column chart of the counts from these ranges. For the 3D residual value grid these ranges are defined by two variables, age and residual value. Practically, they are defined in an intermediate table whose grid cells accomplish the counting and are then visualized in a so-called surface chart. The resolution of the intermediate table, or grid, is age in full calendar years and residual value in $10,000 increments. The residual value grid is colored to enhance its readability. Note that its surface view is an interpolation between the original histogram columns to highlight areas with high numbers of sales, i.e. mountain peaks or ridges, and areas with low numbers of sales, i.e. dips or valleys. The following section shows how residual value grids can be used to determine reliable forecasts for the residual value of individual machines.

6 SAMPLE APPLICATION

The data for the five types and size classes of heavy construction equipment as listed in Table 1, track excavators, wheel loaders, backhoe loaders, articulated trucks, and track dozers are plotted as residual value grids in Figures 2 through 6. All values are inflation-corrected actual dollars. The resolution of the contour lines has been adjusted to reflect the number of data points in each category and to limit the number of categories to at most eight to retain the clarity of the diagram and not artificially introduce a higher resolution in the residual value grid than the amount of available count data in the underlying table merits.

Figure 2 shows the 1,888 observations for track excavators between 25,000 and 50,000 lbs standard operating weight. It is clearly visible that by far the most excavators, over 100, are sold at 4 years of age for around $50,000, after they have experienced a strong loss in value. Two less significant peaks occur at 9 years and $30,000 and at 12 years and $20,000. Overall the sloping down curve in the residual value grid is characterized by a very heavy front, with the largest number of machines having being sold in auctions before they reach 7 years of age, while
it can be hypothesized that older machines are not sold anymore but are retained and used until being scrapped.

Figure 3 shows the 3,857 observations for wheel loaders between 2 and 4 cy general purpose bucket size. About twice as many auction sales for loaders were recorded than for excavators. The loaders show a similar pattern as the excavators, albeit more pronounced. The highest peak with between 120 and 140 machines sales occurs at about 4 years between $60,000 and $70,000. The sales are overall solid throughout the entire range of ages, with a decline between 8 and 10 years and another secondary peak after 11 years of age for about $30,000. It would be interesting to analyze whether the different between these two different groups of machines lies in their manufacturer or condition rating as possible influential factors. It is noteworthy that loaders are still being sold in significant amounts at higher ages than comparable excavators.

Figure 4 shows the 7,530 observations for backhoe loaders larger than 1 cy general purpose bucket size. The residual value grid is overall flatter due to the lower initial price of backhoe loaders as compared to track excavators and wheel loaders. Overall, roughly twice as many backhoe loaders were sold than wheel loaders, resulting in a strong and well-defined curve in the residual value grid. The primary peak is very pronounced at between 4 and 5 years at about $30,000 with over 350 machine sales and the secondary peak occurs at 11 years and $20,000, however, the smaller overall residual value of the machines gives the curve a much more defined ridge.

Figure 5 shows the 1,658 observations for articulated trucks under 50,000 lbs standard operating weight (empty). The residual value grid for this smallest of the five datasets show a much less consistent patterns than the other ones. The down sloping curve is still discernible, ranging from about $180,000 to $30,000 over an age range of 12 years. However, the comparably smaller histogram grid cells from which this residual value grid was composed, with a peak of under 50 machine sales around 6 years and $70,000 that is part of a ridge between $90,000 and $60,000 between 4 and 7 years. The largest amount of the machines has been sold in auctions between $100,000 and $60,000 and 3 and 7 years. Two extensions off the smooth curve shape appear between $140,000 and $120,000 and 3 and 4 years, respectively, and between $60,000 and $40,000 and 10 and 11 years. These two areas may have been caused by the effect of different manufacturers in connection with the perception of the buyers. However, a more detailed analysis would be needed to ascertain this possibility. A traditional statistical scatterplot or box plot, in which the date for each age would have been represented with a solid bar for the main range and whiskers reaching to the extreme observations, would not have allowed this observation. At the same time, the accuracy of using the residual value grid depends on the number of data points that contribute to each grid point and Figure 5 should be considered at the lower end of a desirable size of the dataset with the main body of the residual value grid consisting of between 10 and 20 observations for each grid cell.

Figure 6 shows the 4,594 observations for track dozers between 100 and 200 net flywheel HP. Overall, comparing this figure with another dataset of similar amount of data points and cost, Figure 3, the track dozers exhibit a rather steep initial value loss from approximately $150,000 at 2 years down to $50,000 at 6 years and a noticeably lower slope afterwards to between $30,000 and $20,000 at 15 years. Interestingly, track dozers seem not be sold in significant numbers before they have attained 2 years of age, but are sold solidly until 15 years of age and possibly beyond. The primary peak is found doubly at $80,000 and 3 years and $60,000 and 4 years with between 140 and 160 machines each. Also, the secondary peak is found doubly
at $30,000 between 10 and 11 years and at 13 years. These observations allow the hypothesis that the behavior of the residual value grid can be attributed to an overlay of several different manufacturers with different characteristics of retaining the residual value over the growing age of the machines. On the other hand, the resolution of the residual value grid may also increase originally subtle differences somewhat by placing date points into particular grid cells based on the fixed chosen range limits, so that closely adjacent values may appear more separate. Additional smoothing of the surface chart could reduce this purely graphical phenomenon.

For forecasting a particular residual value for a machine of known age, the equipment manager should stay as close as possible to the ridgeline of the residual value grid. For example, a track dozer of 3.5 years of age should be expected to fetch on average approximately $70,000 in an auction sale. The innovative topographic feature of residual value grids allows the equipment manager at the same time to place high confidence in this estimate, as the residual value grid shows that a large amount of machines have been sold at this value in the past. Price offers in the private market can be gauged against this value. The equipment manager can use this forecasted value as a basis that may be adjusted additionally using professional experience and any available knowledge about the individual strengths and weaknesses of the machine of interest to come up with a very accurate and reliable customized forecast for the residual value.

7 CONCLUSIONS

Residual value is a central consideration within owning costs of used heavy construction equipment. However, until recent research described in this paper and in previous publications, it has remained clouded in uncertainty and equipment managers helped themselves with very broad rules of thumb. Research by the authors has examined large dataset of various different types and sizes of construction equipment. The study was performed with the necessary statistical rigor to ensure reliable forecasts of the regression model that was selected.

In order to facilitate the practical implementation of the results of this study, residual value grids have been devised as an innovative and intuitive graphical presentation of the large amounts of data and to enhance the understanding of the key relationship of residual value with equipment age. Not only are these data clearly shown, but the user can directly judge on the reliability of the data by their height in the topography, i.e., the volume underneath the surface of the residual value grid in a particular area.

In the future, converting residual value into percentages might provide additional insights. It is further recommended to study in more detail the contribution of the different manufacturers that made up the datasets and separate the data by additional characterizing factors, such as condition rating. Previous research has found significant differences in the residual value of construction equipment for these factors (Lucko 2003). A particular area of interest would be to collect and analyze data on how strongly age and meter hours or mileage are correlated and which one of these measures can better predict residual value. Regarding the graphical presentation, overlaying the residual value grids with regression lines could assist reading values from the residual value grid but might give a misleading sense of precision that the resolution of the data with respect to equipment age might not fully support. Smoothing techniques, e.g. moving averages, could enhance the clarity of the residual value grids.

It is hoped that equipment managers are thus enabled to better predict residual value, more accurately determine owning and operating costs for the machines in their fleets, and in the long run contribute to increased profitability of their companies.
Figure 1: Scatterplot of Track Excavators 25,000-50,000 lbs Standard Operating Weight
Figure 2: Residual Value Grid of Track Excavators 25,000-50,000 lbs Standard Operating Weight
Figure 3: Residual Value Grid of Wheel Loaders 2-4 cy General Purpose Bucket Size
Figure 4: Residual Value Grid of Backhoe Loaders >1 cy General Purpose Bucket Size
Figure 5: Residual Value Grid of Articulated Trucks <50,000 lbs Standard Operating Weight (Empty)
Figure 6: Residual Value Grid of Track Dozers 100-200 hp (Net Flywheel)
REFERENCES


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