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A Proposal for an Integrated Methodological and Scientific Approach to Cost Used Forestry Machines

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Abstract

This paper offers a conceptual analysis of the unaccounted-for cost of owning and operating used machines from an operational, financial and market perspective. It is based on input from experts and a literature review. In the scientific literature, assessing the operating cost of used machines in forest operations is typically based on standard cost assessment methods using costing/pricing input from similar unused machines. This is the case since there are usually no historical data for observed used machines available to analyze. This substitute analysis is problematic to many used and depreciated machines owners. The changing trends in forest technology attest that old machinery do not hold to the same input cost data variables or values of new machines. In fact, they belong to two rather competing and different markets: (used vs. new equipment markets). With the technological, market and machinery regulations and dynamic changes, the substitute cost analysis is not representative. Better data is required to understand the cost of owning and operating used machines and the justification is the focal point of this paper. The outcome of the expert and literature analysis in this paper demonstrates that a broader understanding of the cost of a used machine is required and doable. A proposed understanding integrates the machine's availability (performance), cost factors (financial) and market evaluation (price), in isolation (single piece of machine) as well as in a fleet, to assess a used machine ownership cost. The study is intended to offer forest machine operators, owners, scientists, and practitioners a proposed new approach to value used machines and further investigations and data inputs required to make used machines costing methods more relevant.

Keywords: cost assessment, risks, uncertainty, depreciated, equipment, economic machine hours, technical machine hours

1. Introduction

An online search into »depreciated forestry machines costing method« came up repeatedly with one of the most cited studies in the field: Miyata 1980's US Forest Service study on determining fixed and operating costs of logging equipment, as a first return entry. Miyata 1980 and other cost assessments methods (e.g. Matthews 1942, Franklin 1997, Brinker et al. 2002, Ackerman et al. 2014) have costed forestry machines based on their capital cost, predefined life expectancy, interest and insurance rates, repair and maintenance, utilization rate, and labor.

These standard costing methods are also used to cost used machines, because it is expected that the lower purchase price for a used piece of equipment (i.e. lower capital investment) would even out both the higher repair and maintenance expected from used machines (compared to new ones) and their general lower efficiency. However, this assumption carries with it the understanding that all the inputs used to cost a used machine during its operations are addressed if substituted with a new machine (Abbas et al. 2019). Typically, costing inputs are based on estimates of »new machinery« with no operational history that replace the specific used machine being observed or operating on the ground, regardless of how long it has been used. This is because a new machine is the best available alternative estimate of the cost of a used machine. If the machine being studied is out of production, a similar model replaces its value in the cost model, in its new condition, to reach a cost of operations value per Scheduled Machine Hour (SMH) or per Productive Machine Hour (PMH). This means that assumptions made with the substitute new machine speculate no external inputs in the costing method that contribute to the probability of the used machine acting other than new. Because of these assumptions, depreciated machine costs in their current state are rarely well estimated in financial accounting studies.

The caveat of using this approach is that a used machine is less predictable with more unknown risks and uncertainties than a new machine. This is critical, because as machines are used and depreciated, without a case specific documentation of the historical operational details, the cost variability from one machine to another becomes wider and more unpredictable compared to a new machine, as well as the usability of this data to represent the entire fleet being analyzed. Miyata (1980) and others maintained, and this continues to be the case, that a daily recording of operations is required to produce an accurate cost assessment of the operations of the machines. Acknowledging this information, this study does not seek to refute the value of using new machine input data in methods costing used machines, as a rule of thumb when no better data is available. Rather, this study attempts to refine the understanding of costing methods to better integrate the variability of the operational, financial costing and market valuation aspects as significant cost variables in costing used machines[1].

This paper offers a conceptual understanding to help better explain the value of owning a used machine(s) and how the current methods used to assess costs are unrepresentative. Even though many studies have mentioned a fallout in the new machine costing methods analysis (e.g. Bilek 2009), very few if any have proposed a way to better understand the missing components to the shortfall. Further, several studies have attempted to criticize the cost assessment methods part, without accounting for the missing operational or market values to the operator of owning the machines. The inputs to the value of the machine need to account for its operational history and market value to add the relevance of the machine to its value and reliability. In this study, we identify unique elements needed to help build a framework that analyzes existing data or datasets that need to be collected. The authors are currently developing a model analysis and the details of this framework. To expand the analysis, we offer an example of what a used machine analysis would look like compared to a new machine (Fig. 1). The study picks up elements from existing costing methods that need further clarifications and estimations to more accurately reflect ownership cost of used machines. The aim of the paper is twofold:

- ⇒ provide the reader with ideas to test and investigate a new proposed framework
- ⇒ consider with caution new machinery costing methods results of used machines published in the literature.

This paper is structured into three main sections:

- ⇒ the operational section discusses specific operational factors affecting machine performance, availability and utilization and their embeddedness in machine costing methods, as well as differences in emissions, compliance to regulations, ecological effects and the ergonomics of new vs. used machines
- ⇒ the financial section discusses the issue of using new machinery costing methods to assess the cost of used machines. It further discusses the risks and uncertainties attached to the financial cost of owning and operating used machines
- ⇒ the market section delves into the assessment criteria used in the market for pricing a used piece of equipment.

Finally, we discuss how the integration of all three sections present a more accurate representation of the financial cost of owning used machines than the currently used standard new machinery costing methods.

2. Operational Value

The operational value of a machine is based on its availability to perform a productive task. Technical functionality of ground operations is complex, and no single assumption made that is based on historical data related to the performance of one machine fits all other machines cases. Unused/new machines, on the other hand, have set and fixed performance assumptions in place, based on common standards and expected performance rating with minimal, if any, site impacts on the machine. Unlike the case for new machines, not one used machine is going to experience the same working conditions as another performing the similar task. Aspects, such as terrain, operator, lo-

[1] The term »used machine« in this paper refers to all except new machines that are used, secondhand, resale, trade-in and/or partially/fully depreciated

cation, and operational costs, account to a different financial burden per machine. Therefore, oversimplification of machine cost models, with the assumption that new machine capital cost and its depreciation are going to even out this unknown component is not very realistic. With this understanding, owners of depreciated and used machines may not be particularly interested in, or find relevant, the scientific new machines costing methods results (Tennessee Master Logger Program 2016). The key operational question to consider is: Does it matter during the operation if the operator is using a new or a used machine in terms of performance/efficiency? For example, if a used machine with low capital cost is well maintained and performs with the same utilization rate as a new machine, then it would be unrealistic to assume the capital cost of a new machine to cost it. Addressing this question is one of the key purposes of this paper.

A study by Holzleitner et al. (2011) found that »no correlation was found between the amount of repair cost and the annual utilization or the summarized utilization per year«. A possible interpretation of this could be that it is more important how a machine is used and how properly it is maintained, rather than how much or how long it is used. Therefore, the relevance of using a predefined repair and maintenance cost, linked to an assumed fixed utilization rate for a new machine to explain the cost of a used machine, is debatable. Regular maintenance and repair may cause interruptions in performance of a machine to meet market demands (Krivitzky and Yamamoto 2013). However, if a used machine is not maintained over time, there is no doubt that the accumulation of dirt, dust and breakdowns have a toll on the machine performance. Therefore, there is a need for more studies that target the role of maintenance and its relationship with downtimes (Tabikah 2014). There are, on the other hand, agricultural machine models that have shown an increase of repair and maintenance cost rates over the machine lifetime (Edwards 2015), however the downtown associated with these costs requires further investigations.

Compliance to new emission regulations is one of the main differences between the features of old machines and machines that are currently being introduced to the market as new machines and models. Most of the regulations introduced in Europe and the United States lead to more strict requirements for new engines to comply with stricter standards of emissions for HC, NOx, CO, and PM (EPA 2002). In Europe, starting from the Directive 97/68/EC and until the Regulation 1628/2016, there has been stricter standard for engine emissions targeted by different »stages« (from a stage I to a stage V) (OJEU 2016). Similarly, in the US, starting with the federal standards of 1994, until the most recent ones introduced by EPA in 2015, there has also been a lowering of limits of air pollutants defined by different »tiers« (from a tier 1 to a tier 4) (EPA 2019). Hence, new machines cannot be commercialized if not adequately complying with up-to-date environmental restrictions. Indeed, there remains a market for vehicles that are not necessarily comparable to new machinery in terms of environmental performance. However, differences like emission standards could create a disparity between the different levels of machine performance and compliance, which is reflected in their pricing, as well as in different levels of efficiency on lubricant use and fuel consumption.

Emissions-wise, modern machines are expected to have more controlled fuel and lubricant use engines to comply with regulatory concerns of carbon dioxide emissions in the atmosphere and its contribution to climate change. Moreover, internal combustion engines typically show a general performance degradation over time, thus increasing fuel and lubricant consumption. Aged engines are characterized by deposit formation that may change the injector fuel flow rate (DuMont et al. 2009) and the interaction with the in-cylinder flow (Wang et al. 2017). These changes result in worsened emissions (Jiang et al. 2017, Xu et al. 2015, Wang et al. 2014, Joedicke et al. 2012) and increased fuel consumption (Arters and Macduff 2000, Joedicke et al. 2012). In addition, oxidation and soot in the lubricant can result in viscosity increase and the loss of lubricant derived fuel economy (Covitch et al. 1985). Nevertheless, additives and tools for improving the performance of aged engines have been developed and may help reduce fuel consumption and emissions (Krivitzky and Yamamoto 2013, Cui et al. 2016, Aradi et al. 2003). More investigation is required into the increase in emissions of aging engines in forest equipment versus modern ones.

Ecologically, the impact of logging equipment on the ground is more affected by the propulsion device, soil condition at the time of trafficking and number of passes (Cambi et al. 2015). Studies are lacking the account for the age of the machine in relation to impact on soil, for example. However, propulsion devices are periodically replaced or maintained, thus recovering the condition of a new machine. Propulsion device maintenance may play a key role in soil compaction. The main parameter affecting soil compaction is the inflation pressure of tires that should be periodically checked and changed in relation to soil condition, independent of machine age (Cambi et al. 2015, Marra et al. 2018). Also, the damage to regeneration and residual stands are affected by several factors, but the machine age has not been included in the factor list until recently (Picchio et al. 2011, Marchi et al. 2014).

Ergonomically, machines have for long been advancing in many ways targeting reduced noises, vibrations and exposure to external elements using protective gear (Rummer and Smith 1990). Technological advancement, however, meant longer sitting time and less physical activity for the operators (Hansson 1990). Improved variations in machines are recommended to reduce musculo-skeletal problems through rotations and training in work techniques. To a large degree, issues with operator health and safety are not strictly connected with the advancement of the machine only, but also with operator professionalism, as well as accidents, such as unintended activation of switches (Axelsson 1998). Indeed, the workplace has become safer when operators are sheltered from external elements. Therefore, new machine characteristics and old machine characteristics have different sets of unique ergonomic problems.

To summarize this section, used and new machines have different repair and maintenance expectations. The referenced environment/ecology/ergonomic factors are predominantly linked to operating conditions and not necessarily costing elements. From an ecological and emission perspective, used and new machines have different standards. The ecological impact of machinery with different usage has not been widely addressed, however, in terms of emissions, new machines are advancing their requirements to meet tighter standards. Ergonomically, machines are advancing by providing more attention to comfort and sheltered conditions.

3. Cost Assessment, Financial Risks and Uncertainty

As this study seeks to further improve the cost assessment methods of used machines, it must not be forgotten that current »*machine rate models have a number of problems*« (Bilek 2009) and it is not just a matter of using new machines to replace used machines in the financial calculations of cost per productive and scheduled hours (Bilek 2009). Bilek (2009), for example, interrogated the different new machinery costing models available in regard to their applicability to used machines inputs. The »CHARGEOUT!« model is the outcome of his study and is specifically used in determining the financial feasibility of capital investment in equipment. He stressed the importance of integrating the used machine cost factors beyond depreciable life. The model is available free of charge from the U.S. Forest Service online portal and is customizable to the used machine operator and owner. Bilek (2009) as such sheds light on the importance of time value when costing between new vs. used machines. Bilek summarizes this shortage as follows:

»*All machine rate models are based on cost averages. They do not consider the time value of money, do not take into consideration the timing of costs, and are limited with respect to costs that they incorporate. The only rate they calculate is pre-finance and pre-tax. Machine rate models do not do a good job of accounting for financing costs … While the machine rate models can produce cost estimates for new machines, the models are difficult to adapt for used equipment, which may have partially worn replaceable parts. Machine rate models cannot do a good job of incorporating inflation and cannot be used to calculate the rate of return on investment.*« (Bilek 2009)

A prudent operator is expected to build a strong cash-flow for each machine by considering the entire operating system and supply chain. Indeed, mechanized forest operations can be very complex to manage, especially when dealing with both new and old equipment in the same ownership system. Further, the risk and uncertainty of the operations are looked at in terms of the full operational needs of machines and not just the isolated use of one machine. It is expected that as machine owners may own one or two pieces or the entire fleet; dependability of one machine on the other in its sequential operations is going to vary. For example, the loss of one machine may render the second machine useless, unless the first is repaired or replaced.

The lifetime of the machine is usually defined by the treasury departments' time period for depreciation typically used for tax purposes. In the United States, for example, the American Appraisal Associates establishes the »useful life« of equipment categories which the Internal Revenue Service (IRS) uses as a baseline to determine the annual write-off of the machine to the owner (IRS.gov 2017). However, this is purely for tax purposes and may not be very relevant to the true economic life and value of a machine that generates an income to the machine owner. Further, because of the supply chain nature of forest products and production, the economic life of one machine cannot be seen in isolation from another in a supply system.

Risks and uncertainties are the unknown future predictions of possible unexpected machine behavior that may impact operational productivity and earnings from that machine. Risks of these unknown predictions are attached to the chances of uncertainties and may impact the financial cost of owning and operating a machine. Risks and uncertainties may be linked to the machine alone for a single machine owner or as part of the entire supply system for a fleet portfolio management.

Usually, the uncertainties and risks are presented by the probability of occurrence of different types of events during the machine life. As a machine ages and acquires more operating hours – the probability of downtime could increase, as does the probability of potentially higher repair costs. If we focus on utilization, when the machine is new, the probability distribution surrounding the point estimate of the annual productive machine hours would be quite narrow. However, as the machine ages, there would be greater uncertainty/variation surrounding the middle point estimate, as the chance of downtime due to unscheduled failure and repairs would increase. At the same time, the operator and the terrain features would also have an impact on these probability distributions of events, increasing or reducing the effects of downtime on the operational schedule.

The predictability of used machines carries a host of user, region and unknown variables. Although, there is a body of literature that explains the reduction of reliability for older machinery (e.g. Cantú et al. 2017), there is also a body of literature that tends to account for the variability of old machines and their lower operating costs. Sen (1962), for example, wrote an essay on the usefulness of used machines. Further, as an operator gains experience with a specific piece of equipment, there would be a reasonable expectation of a better understanding of its uptimes and downtimes occurrences based on the operator/owner good knowledge of past events and manufacturing data. The more a machine is used, the more information could be acquired about its productivity as well as its reliability.

The availability of such information could increase the operators' awareness of the performance and reliabilities of different machinery, consequently allowing to better guide in the choice of most suitable machinery, as well as estimating more accurately the running costs involved. An example is offered by the Consumer Reports websites and magazines for automobiles; surveying their subscribers regarding aspects that include the reliability of their vehicles, the body, motor, and cooling systems. Similar surveys could be also envisaged for used logging equipment (e.g. www.consumerreports.org 2019). Current computerized machines with more machine learning opportunities may also help improve the understanding and recording of running costs of used machines, as opposed to surrogate new machines. However, it is important to realize that with many older uncomputerized machines in the market, the valuable consumers' and market feedback remain crucial.

For a used machine, the financial risk of paying off the machine depreciation is lower than that of a new machine and maybe even be diminished. This correlates with each working hour, where the impact of paying back the capital investment is generally smaller than that for new machines. However, the operational risk is relatively higher, given that the machine is potentially breaking down more frequently, due to the wear and tear of its components. Under these conditions, the financial burden on the operator in the case of used machine is more approaching the operational one (running/variable costs) than depending on the capital depreciation (fixed/capital costs). The balance between financial expenses is tilted from one that is capital investment based to one that is operationally based. Therefore, in case of used machines, optimal time for replacement (i.e. how long an operator can run used-machines and what is the lifetime of the machine) is a more important question to consider than the traditional cost analysis methods.

3.1 Proposed Costing Approach for Used Machines

Based on these considerations, some different approaches may be used in the financial assessment of used machinery compared to the »standard cost assessment methods«, when including effects of risks and uncertainties:

⇒ purchase price: should include the level of uncertainty linked to accuracy of information on the history of equipment, including the occurrence of its failures, the knowledge of the replacement of main components, past operators' use and the working environments. It should also consider the effect of lowering the investment risk due to possible warranties offered by the dealer. A certification or warranty can be linked to a specific machine after its inspection and the »coverage« could be for one year for example, depending on the machine condition and past servicing (deere.com 2019). Further, additional costs applied to upgrade and/modify parts of a used machine should be added to the total purchase price

⇒ life expectancy: should be defined both in terms of economic life and technical life. The economic life is described when it costs more to own the machine than the income it generates. This timeframe is when the cumulative costs of the possession of the machine exceeds the returns generated during its lifetime, which is generally the period over which the equipment can operate at an acceptable operating cost and productivity. According to Miyata (1980) this is also defined as the time when the cost of lost production exceeds the cost of owning a new piece of equipment, and the equipment owners start to trade for new equipment. The technical life length, on the other hand, is described as the time from whence the machine goes into operation until it is no longer used in any operation (Stokes et al. 1989) independent from the income the machine generates. That is determined by the maximum duration expected for the main components of the machine before reaching the time for replacement. Therefore, the economic life identified for tax purposes is generally shorter than the operational life, which represents the maximum duration of the equipment. As for the purchase price, the expected life should include uncertainty ranges linked to the availability of historical information on the machine past uses

⇒ utilization rates: should be variable along the life of the equipment and reflect the aging of the equipment and the possible changes in the distribution of delays due to the different patterns of machine breakages. An option is to include probability distributions for reliability/failures occurrences at the different ages (Cantú et al. 2017). Further, the utilization rate determination needs to consider, albeit this being more complicated, the downtime across the fleet of machines owned by the same entrepreneur when a whole-system operation is impacted by a single machine. The special warranties or services offered by dealers could also have effects such as to reduce the delays and increase the utilization

⇒ maintenance factors: should also reflect different probability distributions for occurrence of maintenance and substitution costs for the different components, depending on the age, environment and mode of use in the past. Butler and LeDoux (1980) and Butler and Dykstra (1981) allow for initial maintenance and repair costs to be increased exponentially over several time periods. In addition to that, Bilek (2007) uses productive machine hours for modeling such exponential increase rather than years of life. This point is where a concerted effort needs to be made, and more investigations are required, to monitor more cases of used machines based on different ownerships, operating conditions, locations and fleet configurations.

To summarize, current models cost the depreciation of new machines, but never cost partially or fully depreciated used machines in their current state. There is a missing knowledge gap that needs to be customized to used machines in current costing methods. The risk and uncertainty of owning and operating used machines has been hardly covered in the literature. Accordingly, a new method comprised of datasets of machines along their useful lifetime in isolation as well as in a fleet is required.

4. Market Value

The United States and Canada are the World's largest geographic markets for forestry equipment. In 2014, both countries accounted for one-third of the global demand for forestry equipment (including both purpose-built and converted machinery), and their market is forecast to increase by 4.5 percent annually (prnewswire.com 2015). Despite the growth, machine manufacturers markets from both countries view their used equipment inventories as an obstacle to higher sales of new machinery. Large inventories of older used machines pose a risk to the growth of newer models, because of the lower priced commodities, and this issue is persistent. Other aspects such as weak local currencies and high interest rates in countries like Brazil and South Africa hinder the recovery in forestry machines markets (trade.gov 2017). Also, the growth of nations requiring emission standards and regulations, create more technical-barriers-to-trade for used machines that are not up to standards. All of these factors are further contributing to an oddly shaped market for both used and new machinery, which is almost competing. Expenses, such as long hauling of purchased equipment, might further determine the purchase preference of equipment within closer proximity to the operator, especially in the absence of local repair dealers. Hence, in terms of clientele, it would be expected that used machines are going to be more limited to local markets where standards and maintenance are not an expensive unaccounted-for risk to the operators.

The sale of used machines is a growing market. This growth has not gone unnoticed by large manufactures, for example John Deere's and others' catch phrases such as: »*sometimes the best new addition to your fleet isn't new*« seek to promote the sale of certified pre-owned machinery (machinefinder.com 2018) and Caterpillar puts it as »*quality at a price that meets your needs*« emphasizing that used machines are at an affordable rate but not down on »needed« performance (cat.com 2019). This reflects the potential market demand that may not require, justify or reflect the quota needed to pay off more expensive machines. Operators may use second-hand machines as their main machine, irregularly and other times for backup.

In a growing and dynamic market, new machines sales are expected. For example, new machines are introduced when new forest products, technology and equipment markets are expanded, and more resources become available. This is the case, for example, in the Leningrad region of Northwest Russia where imported cut-to-length machines are replacing tree length (Gerasimov and Karjalainen 2012). Technologically new and innovative technologies lead to changes in forestry operations and integrate new technology, for example, it is a de facto for some modern machines to benefit from advancements in global positioning systems, which is not an option available in old machines. Technology does change the way forest operations take place (Guimier 1999). Also, the future of forest machinery has much potential with the extensive big data that connects the extraction, with the processing and delivery of products as well as the technological advancement. However, it remains crucial that operators maintain a basic understanding of the details of how to assess their equity in their assets regardless of accessibility to computerized production data.

According to the International Valuation Standard Council (IVSC 2013), there are usually three general approaches for establishing the value of equipment. The market sale comparison approach, the cost approach and income approach.

⇒ in the market sales comparison approach, a dealer uses »comparable« sales along with dealer listings, auction results, and interviews with dealers specializing in the sale of the type of equipment being appraised. In some cases, an equipment appraiser might be able to find comparable sales of similar equipment with the same manufacturer, year and model number. In other cases, sales or listing information on similar items would be adjusted by specific factors. Some of the factors that are considered when comparing a machine to a comparable one includes: manufacturer, model, effective age, condition, capacity, price, time of sale, type of sale, location, and accessories, amongst other characteristics. The used equipment market that consists of dealers, auctions, and public and private sales is the source of some data. On the top of comparison, also shipping, taxes and other costs for putting in operation the specific equipment would need to be considered. The approach is valid if there is enough market information of similar equipment; if the market-based values are limited, other approaches need to be considered (IVSC 2013)

⇒ an alternative would be the »cost approach«, in this case, an investor would consider the »economic life« of a machine and not pay more for an asset than the cost to replace it with a new (substitute) one. This approach considers the function of the current equipment in use, therefore adjusting the selling price of a new piece of equipment performing the same operations. Adjustment is based on the physical deterioration and functional/economic obsolescence that reflects the current status of the equipment in use. The cost method is typically more important if equipment does not have an active market because of a unique or highly customized scenario (IVSC 2013)

⇒ the income approach, on the other hand, uses the future income stream that a piece of equipment or machinery might create to estimate its value »the technical life«. However, it is difficult to directly associate the equipment and economic return from it. Present value of income streams generated by a machine is estimated by the appraiser and it is valued based on discounting to present, a discount rate is calculated to consider return on investment and risk (IVSC 2013).

Datasets such as »EquipmentWatch@« collect a fee to provide information on market pricing trends using an economic index to monitor market changes in prices and trends over time. Price trends are month to month and year to year. Trends are based on equipment types, brand values, usage, market activity and age, as well as regional trends, where regions with very little or no market activity are excluded from the analysis (EquipmentWatch 2018).

However, these trends reflect already defined prices for used machines and do not inform them. Tools are also available online (e.g. www.usedequipmentguide.com/price-calculator), and they help perform an estimation of purchase prices for used equipment. In such tools, the user could also query the price of most common forest machinery (e.g. harvesters, forwarders). The query is based on the selection of machine brand, model, year of production and lifetime (hours in machine meter), however there is no possibility to access the mechanism behind the relations used for assessing the prices.

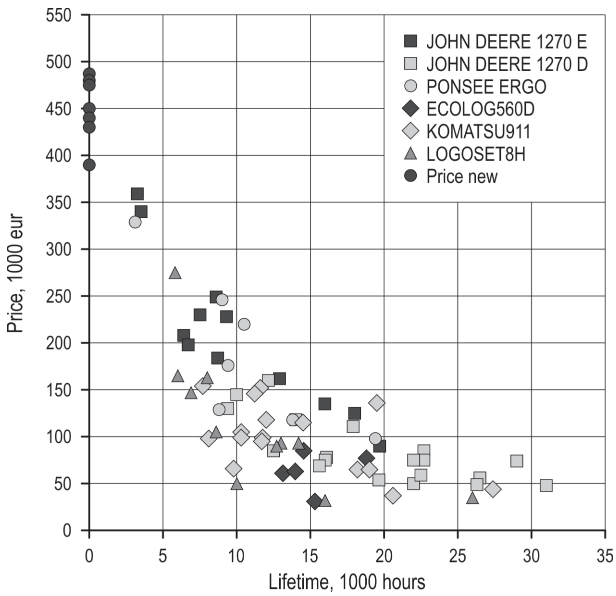

Fig. 1 An example of market information to help determine the selling prices and lifetime relation of most common models of used (over 0 use hours) wheeled harvesters observed in the EU (information collected from wwww.mascus.com in 2019) and purchase price for new models of similar harvesters (collected from BWF, Austria, https://bfw.ac.at/fmdb/ in 2019)

Scientific models have attempted to compensate for this lack of information by trying to find a correlation between posted largescale second-hand machine datasets, to help develop a cost and usability relationship to help an owner benefit from their ownership experience of machines and to help lower a manufacturer's asking price for warranty (Ireland 2009, Kwak et al. 2012). Malinen et al. (2016) analyzed forestry machines data from the machinery sales website: www.mascus.com, a leading online secondhand machines portal. It was found that market costing mechanisms were inconsistent; at times based on age while on other instances based on usage of certain machines. Further, regional variations were another factor that determined the type of used machines available for sale. For example, newer used models were found to be sold in northern Europe, whereas older used models were found to be sold in eastern Europe (Malinen et al. 2016). The access to this information could allow observing the relations similar to those between the selling prices[2] of common forest harvesters in the EU and their lifetime as in Fig. 1. Similar analysis could be performed for different regions. As an example, in North America (US and Canada) the use of selling prices, auctioning prices and lifetime from websites such as www.forestrytrader.com could allow building similar relations as in Fig. 1.

Paying the cost for a warranty policy of a machine and what it may cover makes it more predictable to assess the repair and maintenance costs of what is covered in the policy. This calls of course for expected transparency between the market and the machine owner or buyer about the details of what a warranty and service contract may or may not cover. Warranty time is assumed to be up to 12 months (deere.com 2019). It becomes easier under these circumstances for the operator to cost the machine based on the warranty plus the consumables used by the operator such as fuel, lube and wear parts. In the United States, for example, the Unified Commercial Code (UCC), a form of implied warranty under a unified United States commercial law, implies warranty on the sale of secondhand goods. However, it is difficult to determine which used goods are considered merchantable and which are not (Kimmel 2013).

Broad industry conversations have shown that used machinery assessments are based on the predicted life of the machine to define a certified-used warranty for a specific period, physical inspection and uptime and downtime understanding being important assessment criteria. The reliability of a machine has a large effect on its cost to the owner. Reliability in that sense accounts for the machine, its history and familiarity of the operator with the machine. A physical inspection is expected to be thorough and covers tires to machine structures. Without equipment warranty, and even with warranty, an operator needs to keep track of how much the machine is costing per month. Machines have gone from a manual to a computerized system that tracks every detail. Currently, the market is mixed. For those very reasons, the market portion is broader than the financial costing and performance – but this is what the operator is going to pay to buy a used machine (or determine the resale price of the machine).

The market for used and new machines is significant. Scientific and commercial models have attempted to improve the machine ownership experience by estimating a statistical relationship between machines and posted market values. Implied warranty in the sale of used machines is not something to be relied upon. With the introduction of more computerized systems, the data available to machine owners and the market are converging and eventually this would lead to a clearer trend of costing used machines. However, the market for uncomputerized machines and its

[2] Assuming that the selling prices approximate the final auctioning price of the machinery

small-scale users still exists. More effort is required to help increase transparency between the machine owners and market pricing mechanism of equipment since it is not as straightforward as a financial assessment.

5. Discussion

In this study, we propose an alternative to the de facto new machine cost approach for assessing the cost of used machines. Our approach in turn promotes the importance of considering the affordability aspect of the ownership decision. Operators and machine owners are, to a large degree, struggling to make a profit (Spinelli et al. 2017, Regula et al. 2018) and as such it is crucial to explain the multiple factors that set the value of the machine. Accordingly, the market valuation of the used machine needs to be better understood in conjunction with the operator's knowledge of the operational value and financial cost of the machine. The proposed methodological concept of the value of a used machine to the owner in making ownership investment is based on understanding three distinct values: that of the machine availability (operation), cost (financial fixed and operating cost criteria) and price (market dynamics).

With used machines, especially, there is no one form of analysis that fits all cases. Indeed, daily accounting of the operational cost of used machines are critical, however, the relevance of even this daily information to the market posted values of machines is unclear. The collection of longer-term performance data of used machines is lacking. Therefore, more field data are required to build a more rigorous model for used machines. For example, more surveys and data collection from source could help improve understanding of machinery performance, but also as machines advance, data collection would be expected to be more automatic using software to collect this information.

An operational value would seek to assess the machine downtime and uptime and assessment in relation to the fleet portfolio; a financial assessment would seek to assess fixed and variable expenses of the machine, with more weight on the operational expenses of actually running the machines. However, if such variables are not available, then the owner might use market values of the used machine capital cost values and not new machine values and focus more on the variable costs of operating the machine, such as consumables and non-consumables. As the operational and cost value of the machine is compared with the posted market value of similar machines, an operator may decide the worth of owning the machine. However, this worth may have little to do with the market value as an owned used machine serves the operator in a more versatile manner than a potentially new machine would.

A simplified cost assessment method of used machines would require market-based and operational-based calibration of a model coefficient to be used in a tailored cost model. This would require dedicated time tracking and cost commitment over the lifetime of the machine. With this in mind, this study recommends basing the callibration on data collected from previous studies, existing used machines and gradual update with information about the performace of newer models of the used machines. Further research and data are required to collect all the information necessary to evaluate all three aspects of the owneship decision.

The proposed costing concept requires the collection of the following data for the used machines cost assessments:

⇒ a value set for the operational value and reliability of a machine

⇒ as much as possible understand the costs of repair and maintenance of the existing machine, knowing that it is already depreciated, hence the weight is more on the operational variable costs of the machine than on the fixed capital cost

⇒ market advisors could help explain further the costing mechanism used to determine the pricing of used machines.

Our proposal for an integrated more pragmatic methodological and scientific approach to costing a used machine would entail:

⇒ develop similar examples to figure one that presents market information that monitor used machines targeting a set of field data collected from different machines in isolation as well as from their performance as part of a fleet. For example, this may help understand the selling prices of used machinery based on different technical lives – as it shows the number of hours – as the duration of the machines indicates when to replace (economic life) or continue to operate (technical)

⇒ produce examples that demonstrate errors/variability of hourly costs compared with the de facto new machinery details. Albeit no one size fits all, but a large enough sample with conditions of operations in mind might develop a more relevant operational rate for different types of machines based on their usability

⇒ develop a coefficient factor that may be compared to the standardized new machinery inputs in the costing method

⇒ collect values more sensitive to the used status of the machine.

This used machinery analysis offers a new understanding, which not only observes the Scheduled Machine Hours (SMH) or Productive Machine Hours (PMH) but also the Economic Machine Hours (EMH – when a machine ceases to produce a profit and is replaced) and the Technical Machine Hours (TMH – when a machine reaches the end of its life, regardless of profit over a replacement). This is key, since it does not cost the same to own an idle used machine compared to an idle new machine – reflected in the SMH. This new look into the used machine ownership experience analysis is missing in the literature. Not only is this aspect missing, but also the economic benefit from owning a machine that has been maintained is compared to another used machine equally by comparing both to a new machine in cost assessment methods is misleading. Several studies have indicated that structured management techniques and advanced decision support and diagnostic tools can help minimize maintenance and repair costs over the lifetime of machines (National Academy Press 1996), making repair and maintenance optimization both a technological and economic necessity (Dekker 1996).

6. Conclusions

Developing estimates that target the operational value of the machine, plus its costing methods data input, with market regional, age, hours and model aspects may help define a better understanding of the value of the used machine. Valuing a machine based on its availability, financial assessment and market price is a more realistic costing value to the owner of a used machine.

Further studies are required that compare consistently new versus used machines repeatedly over an extended period. The lack of such studies has resulted in preference to cost modeling of used machines based on new machinery data with more predictability of performance. Data collection modes, such as surveys of used machines or machine lifetime details of performance, are required to validate results. However, it is expected that machine modernization that automatically collects performance data integrated with ownership cost would result in more detailed descriptions unique to every machine along the supply chain, based more on empirical as opposed to alternative new machinery data estimates.

To conclude, this study offers a step to help provide the reader with ideas to test and explore further and to take new machinery costing methods results of used machines published in the literature cautiously. The elements and drivers of costing a used versus a new machine are different and as a result the need to integrate the operational and market values with the financial accounting cost provides a more accurate estimate of the machine's value. Operational and market factors articulate further the used machine value because they observe and account for the »used« nature of the machine. These factors are more current and do not compare the production capacity of both new and used machines, nor do they under or overestimate the wear and tear value of used machines. Further, despite the clear significance of the market in identifying the sale, resale and trade of used machines, the mechanisms themselves to define the value of a used machine are not clear and may vary with region, age, model, and other dynamics. Hence, the current methods that cost used and new machines with the same inputs and methods are unrealistic.

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