Repair and maintenance costs of 4WD tractors and self propelled combine harvesters in Italy

Aldo Calcante,[1] Luca Fontanini,[2] Fabrizio Mazzetto[3]

[1]Department of Agricultural and Environmental Sciences, Università degli Studi di Milano, Italy; [2]Effelle Solution, Italy; [3]Faculty of Science and Technology, Free University of Bolzano, Italy

Abstract

Purchasing and maintaining tractors and operating machines are two of the most considerable costs of the agricultural sector, which includes farm equipment manufacturers, farm contractors and farms. In this context, repair and maintenance costs (R&M costs) generally constitute 10-15% of the total costs related to agricultural equipment and tend to increase with the age of the equipment; hence, an important consideration in farm management is the optimal time for equipment replacement. Classical, R&M cost estimation models, calculated as a function of accumulated working hours, are usually developed by ASAE/ASABE for the United States operating conditions. However, R&M costs are strongly influenced by farming practices, operative conditions, crop and soil type, climatic conditions, etc. which can be specific for individual countries. In this study, R&M cost model parameters were recalculated for the current Italian situation. For this purpose, data related to the R&M costs of 100 4WD tractors with engine power ranging from 59 to 198 kW, and of 20 SP combine harvesters (10 straw walkers combines and 10 axial flow combines) with engine power ranging from 159 to 368 kW working in Italy were collected. According to the model, which was obtained by interpolating the data through a two-parameter power function (proposed by ASAE/ASABE), the R&M cost incidence on the list price of Italian tractors at 12,000 working hours (estimated life of the machines) was 48.6%, as compared with 43.2% calculated through the most recent U.S. model while, for self propelled combine harvesters, the R&M cost incidence at 3,000 working hours was 23.1 % as compared with 40.2% calculated through the same U.S. model.

Correspondence: Aldo Calcante, Department of Agricultural and Environmental Sciences, Università degli Studi di Milano, via Celoria 2, 20133 Milano, Italy.
Tel. +39.02.50316854.
E-mail: aldo.calcante@unimi.it

Key words: repair and maintenance costs, 4WD tractors, self propelled combine harvesters, cost estimation models.

Contributions: the authors contributed equally.

Conflict of interests: the authors declare no potential conflict of interests.

Journal of Agricultural Engineering 2013; XLIV(s2):e70
doi:10.4081/jae.2013.s2.e70

Introduction

Purchasing and maintaining tractors and operating machines are two of the most considerable costs of the agricultural sector (Buckmaster, 2003; Mazzetto and Calcante, 2010), which includes farm equipment manufacturers, farm contractors and farms. In particular, for farms, mechanization costs can constitute 15-50% on the total costs of crop production (mean data related to field crops, E. U. FADN, 2007).

The operating costs of an agricultural machine are calculated using methodologies that are similar to those employed for calculating a balance sheet. Briefly, a balance sheet consists in the registration of a series of economic events linked to the flows of materials (or services) in input or output categories. At the end of a financial period, all the budgeted entries are included in the so-called final balance, *i.e.*, the result of the economic activity of a company. In our case, it was necessary to apply analytic accounting rules by dividing investment over a predefined number of years (amortization) and adding all the items that, in a specific year, represented the real cost of agricultural machines (taxes and insurances, hours of ordinary maintenance, spare parts, etc.) and the overall costs due to consumables, which are directly proportional to the effective working hours of a machine (for example, lubricants, fuels, etc.)

It is even possible to calculate a capital budget, which is a kind of forecast of the economic events that are expected to occur during a productive period. This strategy allows predicting potential costs of materials (supply of production factors) and financial terms, such as allotted capital or funds for the acquisition of new resources. Compared with a final balance, the budget is obviously more simplified because it is not based on real items. Moreover, the economic scenario of a tentative budget is based on a rational hypothesis that depends on former experiences. In addition, the estimated cost of agricultural machines is usually calculated when planning a new purchase or when assessing the performances of possible alternative scenarios that involve the use of different machines. Because real data are not available, the calculation methodology is based on simplifications and conventions that estimate single item costs, usually split in annual ownership costs and annual operating costs. In this context, repair and maintenance costs (R&M costs), which are included in annual operating costs, represent about 10-15% of the total mechanization costs (Rotz and Bowers, 1991). R&M costs tend to increase depending on the age of a machine and, hence, become an important criterion in determining the optimal time to replace machine itself.

Farm equipment manufacturers design agricultural machines to perform for a maximum number of hours, which is called "estimated life" (Df, hours). Considering the physical wear of tractors and self propelled (SP) combine harvesters, and the current construction technology, the life of a tractor ranges between 10,000 and 14,000 hours (up to 16,000 hours for high power tractors, Lazzari and Mazzetto, 2009) whilst the life of a SP combine harvester is estimated to 3,000 hours. Yet, the estimated life is highly variable for each type of machine because it depends on its use. Specifically, the estimated life depends on several factors, such as intensity of use per year, propensity to buy new machines to maintain a high technological level, quantity and quality of ordinary maintenance, and compliance with programmed extraordinary maintenance intervals (for example, rebuilding the clutch and brakes). Theoretically, R&M costs could be a function of the intensity of use of a particular machine, at least, for some wear parts. However, other factors are involved in R&M costs, such as operative conditions, crop and soil type, climatic conditions, mean engine load required by different operations, and machine maintenance level. Because of the aforementioned difficulties, the most convenient method to correctly estimate R&M costs is based on a modeling approach. Therefore, the R&M cost estimation requires a calculation model that is 1) appropriate for the temporal dynamic of predictable expenses of different machines types and 2) able to extrapolate average behaviors from a sufficiently wide sample.

At the methodological level, different models are available for calculating R&M costs. One the most well-known and used model is the one proposed by Bowers and Hunt (1970), which is a three-parameter model that starts with R&M costs associated with a large sample of machines. Fairbanks *et al.* (1971) developed two models with data collected through interviews related to a sample of 114 farmers from Kansas: one model referred to tractors (2WD and 4WD) and the other model referred to self-propelled harvesting machines. The model proposed by Fairbanks *et al.* (1971) is based on a two-parameter equation (power function) suggested by the ASAE D 230.1 (1966). This model estimates the repair and maintenance costs according to equation (1)

$$\mathrm{Crm} = \mathrm{RF1} \cdot \left(\frac{h}{1000}\right)^{\mathrm{RF2}} \quad (1)$$

where:
Crm = total cumulative repair and maintenance costs (expressed as the percentage of the list price of a machine);
h = working hours accumulated by each machine.
RF1 and RF2 = dimensionless coefficients that affect the shape of the interpolating curve.

In particular, RF1 describes the amount of R&M costs while RF2 represents the distribution of R&M costs during the estimated life of a machine (Sartori and Galletto, 1992).

Nowadays, the standard applied at international level is the ASAE D497.7 (2011), whose RF1 and RF2 parameters are calculated for the U.S. operating context. Obviously, since the R&M R&M costs are strongly influenced by farming practices, operative conditions, crop and soil type, climatic conditions, etc. which can be specific for individual countries, it would be necessary to adapt the RF1 and RF2 parameters to specific local situations in order to refine the results of cost calculation methodology (Ward *et al.*, 1985; Rotz, 1987; Morris, 1988; Gliem *et al.*, 1989; Wahbi and Al-Suhaibani, 2001; Frank, 2003; Knoub Bacht *et al.*, 2008).

Table 1 shows the RF1 and RF2 parameters proposed by ASAE D497.7 (2011) for 4WD tractors and SP combine harvesters, respectively, the values of Df (in hours, estimated life of machines) and total life of R&M cost: this latter parameter represents the amount of R&M costs, expressed as a percentage of the list price, used for maintenance and repairs on average during all the Df period of machine.

Total life of R&M costs are expressed as a percentage of the list price. For 4WD tractors, at 16,000 accumulated working hours ASAE D497.7 (2011) standard estimates R&M costs equal to 76.8% of the price list whilst, for SP combines, at 3,000 accumulated working hours the same standard proposes an incidence of R&M costs equal to 40.2% on the price list of the machine. The objective of the present work was to collect and analyze real data on the R&M costs of tractors and SP combine harvesters working in Italy in order to recalibrate RF1 and RF2 parameters to have a predictive model suitable for the local situation. The obtained models would provide planners, manufacturers of agricultural machinery and farmers with an opportunity to evaluate the economic performances of tractors and SP combines in Italian contexts. The possibility of using local models allows to carry out accurate economic analysis of agro-mechanical investments and enables to help farmers and contractors to take the better decisions related to farm mechanization planning (for example it is possible to carry out comparison between different extended warranty plans, Calcante *et al.* 2013); indeed, all these aspects are based on the estimated costs of agricultural machine use.

Materials and methods

The present study compiled data on the R&M costs (ordinary and extraordinary) of tractors and SP combine harvesters belonging to farmers and contractors working in Italy. The research considered 100 models of 4WD tractors of several brands (Italian and foreign) with engine power ranging from 59 to 198 kW, and 20 SP combine harvesters (10 straw walkers combines and 10 axial flow combines) with engine power ranging from 159 to 368 kW. Considered SP combines were used especially for grain and ear corn harvesting. Three of them were used also for rice harvesting. The characteristics of the considered population of machines are summarized in Table 2.

The mean ages of the sampled machines was 8 years (minimum, 1 year; maximum, 22 years) for tractors and 9 years for SP combines (minimum, 2 year; maximum, 19 years). Noted that mean annual use of tractors was clearly higher than the Italian average (less than 500 h/year for tractors, Pawlak *et al.*, 2001), but it was lower than the U.S.

Table 1. RF1 and RF2 parameters proposed by ASAE D497.7 (2011) for 4WD tractors and SP combine harvesters.

Machines	RF1	RF2	Df (h)	Total life R&M cost (%)
4WD Tractors	0. 300	2.000	16,000	76.8
SP combine harvesters	4.000	2.100	3,000	40.2

Table 2. Characteristics of the considered population of agricultural machines.

Machines	Sample size		Power (kW)	Working hours (h/year)	Age (years)
4WD tractors	100	Min.	58	213	1
		Max.	198	2,217	22
		Ave.	113	798	8
SP combine harvesters	40	Min.	151	197	2
		Max.	368	833	19
		Ave.	236	367	9

average (970 h/year, Pawlak *et al.*, 2001). For SP combines, no data are available in literature. A survey conducted by us in collaboration with some of the most important farm equipment manufacturers (CNH and John Deere), indicated about 500-600 h/years as mean annual use of SP combines in U.S. operating conditions.

To achieve a satisfactory level of completeness of the dataset, data related to maintenance and repair costs were collected using the following sources:

1) Direct contact with tractors' and SP combines' owners (filling forms). In this way, it was possible to collect data related to the maintenance activities performed in farms' workshops.
2) Queries to dealers' and authorized workshops' databases, in which ordinary, programmed and extraordinary maintenance interventions are registered. These databases represented the most complete source of repair and maintenance activities (especially extraordinary and programmed activities, with relative R&M costs) that are rarely performed in farms.

The costs of ordinary maintenance were obtained from information provided by tractors' and SP combines' owners and, in the absence of such information, from the reported information on the use and maintenance manuals of each single machine. The cost of labor for ordinary maintenance was estimated to be 35 €/hour (this value was corrected for inflation as a function of the moment of the intervention). Lubricant costs were not considered because such costs are conventionally included in the cost calculation of consumable materials (fuels and lubricants). Therefore, we considered only the labor cost necessary for replacing lubricants. Thus, an accurate and complete survey was obtained as a result of the completeness of the dataset. Unlike other papers, where R&M costs were grouped on an annual basis, here, they were linked to working hours measured at the moment of ordinary or extraordinary maintenance interventions. From the operative point of view, recorded data were managed and assembled through a normal spreadsheet (Microsoft Excel 2010). Once data from all the considered machines were grouped, the R&M costs – expressed as a percentage of the list price as a function of the accumulated working hours – were plotted on two two-dimensional plots, one for tractors and one for SP combines. Interpolation of values performed through a two-parameter power function allowed us to calculate RF1 and RF2 parameters for tractors and SP combine harvesters working in Italy.

Results and discussion

Table 3 shows the average, standard deviation, minimum and maximum values and the coefficient of variation of all the considered machines.

According to Bowers and Hunt (1970) and Rotz (1987), the high variability of data present in this type of analysis is evident. Indeed, for tractors, the coefficient of variation of labor is 70%, that of spare parts is 84%, and that of accumulated R&M costs is 77%. For SP combines, the coefficient of variation of labor is 53%, that of spare parts is 42%, and that of accumulated R&M costs is 40%. Therefore, such costs are not dependent only on the age of the machine and its yearly working hours. The high observed variability likely depends on the following factors: a) the fulfillment of programmed maintenance plans; b) the engine power and list price of a machine (*i.e.* more powerful tractors are involved in heavy operations and, therefore, are subject to higher wear); c) the intensity and modality of use of a single machine (tractor and SP combine); and d) the ability of driver.

Therefore, obtaining a general model that is useful for each farm and each specific machine is difficult because of the need to consider several different variables (Ward *et al.*, 1985). Because we were able to compile information for each single machine, it was possible to assign several extraordinary maintenance interventions to the involved electromechanic parts. Figure 1 highlights the part that required more extraordinary maintenance interventions for 4WD tractors and SP combines. For tractors, the part most subject to issues was the engine (25 % of total interventions), followed by the electronic system (18%) and the transmission (15%). Because tractors are normally involved in heavy operations, the engine and transmission are the most vulnerable parts to wear and breakage. In contrast, the electronic system is surprisingly the next most vulnerable part. Certainly, the electronic system is open to significant improvements, especially concerning its reliability. For SP combines, the component that required more extraordinary maintenance events was the header unit (49.3%) followed by the threshing system (12.5%), the hydraulics (8.2%) and the classic wear and tear parts (feeder conveyor, 7.6%, grain tank unloading auger, 6.9%).

To estimate the RF1 and RF2 parameters for tractors and SP combines, the interpolation of R&M cost values, referred to list price and expressed as a function of accumulated working hours, was performed using equation (1). The obtained model (2) for 4 WD tractors presents $R^2 = 0.82$, RF1 = 1.945 and RF2 = 1.295

$$Crm = 1.945 \cdot \left(\frac{h}{1000}\right)^{1.295} \tag{2}$$

while the model for SP combine harvesters (3) presents $R^2 = 0.80$, RF1 = 4.095 and RF2 = 1.591

$$Crm = 4.095 \cdot \left(\frac{h}{1000}\right)^{1.591} \tag{3}$$

Table 3. Variability of labor, spare parts accumulated working hours and R&M costs of the considered machines.

		Labor (€)	Spare parts (€)	Accumulated working hours	Accumulated R&M costs (€)
4WD tractors	Average	5,098	11,671	5,626	15,702
	Standard Dev.	3,595	9,780	2,955	12,085
	Minimum	77	79	400	319
	Maximum	18,935	50,001	15,450	60,621
	CV	70%	84%	55%	77%
SP combine harvesters	Average	5,554.65	25,374.52	2,996	30,739.70
	Standard Dev.	1,664.83	10,731.10	1,211	13,425.34
	Minimum	1,496.00	9,824.89	1,200	12,448.39
	Maximum	10,565.05	47,862.80	4,970	58,269.30
	CV	53%	42%	40%	44%

Clearly, both models are the result of R&M cost analyses – based on real data - on a non-homogeneous sample of machines. In this population, in fact, it is possible to find: a) new and old machines with few working hours that have undergone only the ordinary maintenance, b) tractors and SP combines with high number of working hours and high number of ruptures, c) new machines with high number of working hours and high number of repairing. It is reasonable to expect that the age of the machines (in terms of years since their first registration, or construction, *i.e.* its calendar-age) can somehow influence on the cost of R&M, due to phenomena related to natural aging of individual components. However, these phenomena act in combination with the direct wear due the actual operation of the machine and the models proposed so far tend to see the effects due to these causes prevailing as compared to the calendar-age of the machines. To this aim, it should be mentioned that also the engine load may influence the course of R&M costs along timeline: regular use of machines in heavy work enhances wear phenomena, especially for tractors. These considerations would lead to the definition of estimation models with a greater number of variables, with the need to redefine the methods of investigation and render useless comparisons with conventional models used so far. Therefore, in this study we considered useful to apply again the approach already proposed by Bowers and Hunt (1970) that evaluates the accumulated R&M costs of each machine with its accumulated work hours.

The resulting pattern for 4WD tractors compared with the ASAE D497.7 (2011) model is highlighted in Figure 2 (we assumed Df of 12,000 hours for tractors, which corresponds to total life of R&M cost = 48.6%). From a strictly theoretical point of view, for tractors, it would be possible to extend the Df value (Df = 16,000 hours, total life of R&M cost of 70.5%, a smaller value than that estimated by the U.S. model, table 1). However, considering that the analyzed population of tractors has average annual working hours of 798 hours, the estimated life of each tractor would be 15 years. This value does not coincide with the amortization period, which is usually estimated in 12 years for these categories of tractors (Lazzari and Mazzetto, 2009). Further, this value not only has economic meaning but also represents the time point when it is advisable to substitute a machine for technical limits, better safety and comfort as well as to reduce the environmental impact of the equipment. In other words, increasing the years of estimated life might mean owning technically obsolete machines for farmers and contractors.

For 4WD tractors, the R&M costs in Italy are higher than those in the U.S. (48.6% vs. 43.2%). In particular, the maximum distance between the two curves corresponds to 7,600 working hours (Crm = 27% and Crm = 17% of price list, respectively). Moreover, the two curves tend to converge in the proximity of the end of the estimated life. Indeed, with a hypothetical Df of 16,000 hours, the two curves practically show sim-

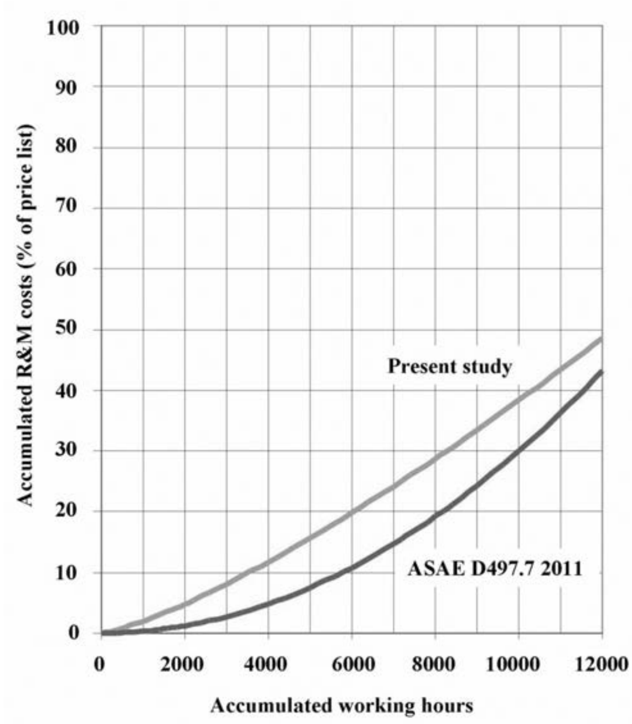

Figure 2. Comparison between our model for 4WD tractors (Present study) and that proposed by ASAE D497.7 (2011).

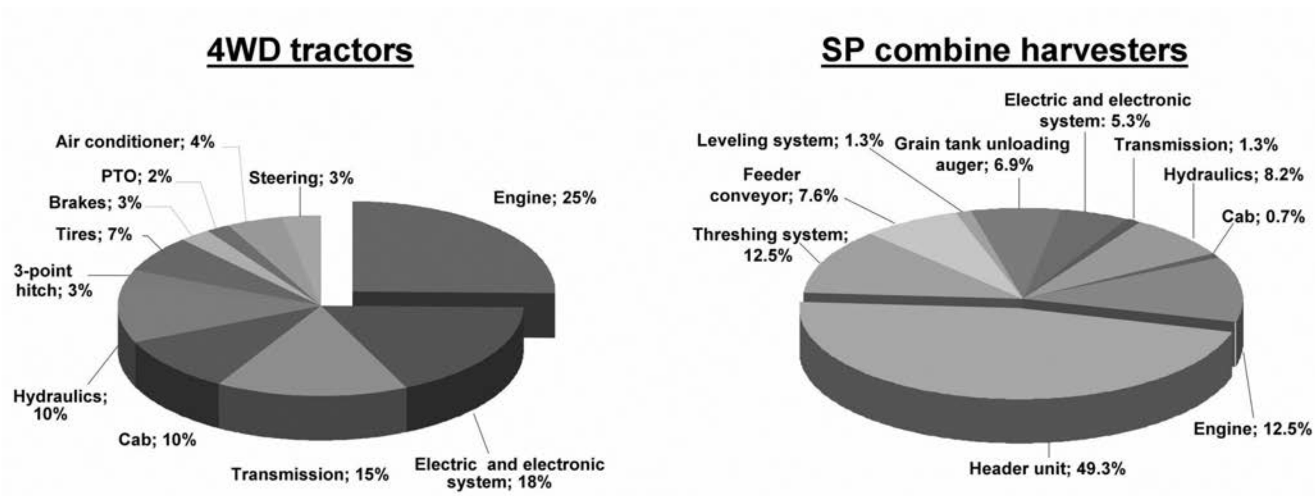

Figure 1. Distribution of extraordinary maintenance events as a function of the considered agricultural machine parts.

ilar values at approximately 14,000 hours. This means that, in Italy, we have a greater incidence of Crm than estimated by ASAE D497.7 (2011) especially for the younger machines with high number of working hours. So, this is an important criterion in order to choose the right time for the tractor substitution, both for contractors (who tend to substitute, anyhow, their tractors more frequently than farmers) and farmers that often keep obsolete and uneconomic machines in their fleet of tractors.

For SP combine harvester, we obtained opposite results (Figure 3): in U.S the R&M costs are much higher than those obtained in Italy. In fact, considering Df = 3,000 hours, the model proposed by ASAE D497.7 (2011) for U.S. context, estimates a R&M costs incidence = 40.2% whilst our model only 23.1%. This means that, in U.S, there's a greater incidence of Crm than in Italy probably due to the different intensity of use (over 500 vs. 367 h/year) and to the different operating conditions in the two countries. Further, it is important to note that RF1 and RF2 parameters proposed by ASAE/ASABE are related to generic "self propelled combines" whilst our research has considered particularly SP combine harvesters for wheat and ear corn (the most diffused crop productions in Italy). On the other hand, is the crop that requires the adoption of a specific header unit and, as a consequence, determines the machine working parameters in terms of energy requirements, working speed, rpm of engine and threshing systems etc.. This, certainly, has a great influence on breakage and wear and tear of specific mechanical parts (Srivastava *et al.*, 1990; Mao *et al.*, 2007).

In conclusion, the differences between the ASAE D 497.7 models and models calculated for the considered agricultural machines operating in the Italian context are evident. This confirms the need to recalibrate RF1 and RF2 parameters for local conditions.

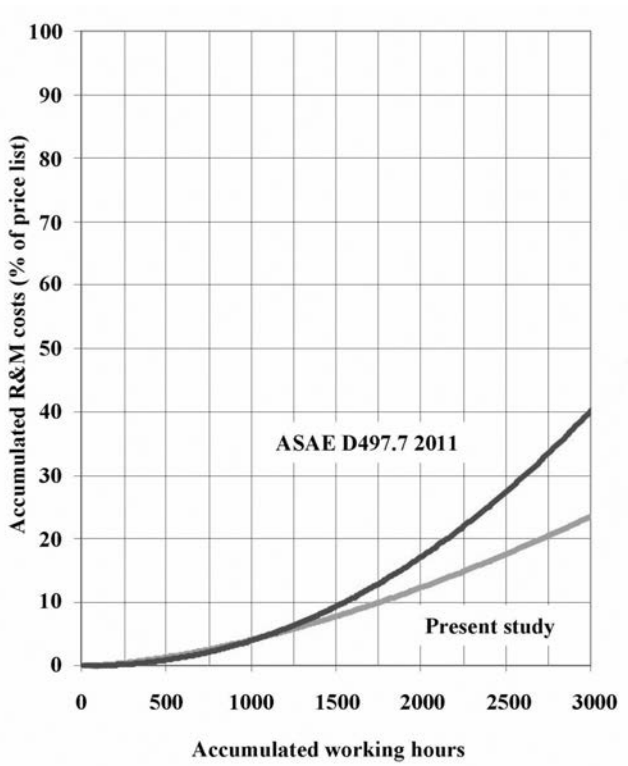

Figure 3. Comparison between our model (Present study) for SP combine harvesters and that proposed by ASAE D497.7 (2011).

Conclusions

The aim of the present work was to calculate - for the Italian situation - the RF1 and RF2 parameters of the model based on a power function normally used to estimate R&M costs of 4WD tractors and SP combine harvesters. Data on ordinary and extraordinary maintenance interventions of the considered machines were collected through direct contact with tractors' and SP combines' owners and through queries to dealers and authorized workshops' databases. The obtained results were compared with results reported in the last release proposed by ASAE/ASABE (ASAE D497.7, 2011) that are currently the standard for this type of analysis. Our model for 4WD tractors shows that, for a total life of 12,000 hours, the R&M costs (expressed as a percentage of the list price) are 48.6%, whilst model related to SP combine harvesters shows that, for a total life of 3,000 hours, R&M costs are 23.1%. The comparison between our models and the most recent ASAE models showed higher incidence of R&M costs in the Italy than in the U.S for tractors and an opposite behavior for SP combines. Therefore our results confirm the need to have models based on local conditions in order to improve the R&M costs estimation for each agricultural context. For future, it would be useful to increase the sample size and to create an operational tool at a national level that is able to collect data linked to the maintenance and repair interventions of agricultural machines. However, such information system cannot be successful without the adoption of telemetry devices and/or operating monitoring systems installed on-board of tractors. Thus, the collection process of work parameters related to agricultural machines would be completely automated. Some tractors and SP combines are already provided with built-in devices to continuously monitor their performances. In other situations, it is possible to adopt data-loggers, normally employed for the monitoring of farm activities, for managerial purposes (Mazzetto *et al.*, 2009). In any case, a complete and objective analysis can be performed on a large scale only with the participation of farm equipment manufacturers, dealers, agro-mechanical companies and farmers' associations.

References

ASAE STANDARDS, 58th D497.7: Agricultural machinery management data. St. Joseph, Mich.: ASABE; 2011

ASAE STANDARDS, 13th D230.1: Agricultural machinery management data. St. Joseph, Mich.: ASAE: 1966

Bowers W, Hunt DR, Application of mathematical formulas to repair cost data. Trans. ASAE 1970;13:806-9.

Buckmaster DR, Benchmarking tractor costs. Applied Eng in Agric 2003;19:151-4.

Calcante A, Fontanini L, Mazzetto F, Repair and maintenance costs of 4WD tractors in Northern Italy. Trans ASAE 2013;56:355-62.

E.U. FADN; 2007. Available from: http://ec.europa.eu/agriculture/rica/index.cfm.

Fairbanks GE, Larson GH, Chung DS, Cost of using farm machinery. Trans ASAE 1971;14: 98-101.

Frank L, Coefficients of repair and maintenance costs for axial and transverse combine harvester in Argentina. Span J Agric Res 2003;1:81-97.

Gliem JA, Persinger KM, Carpenter TG, Holmes RG, A comparison of ASAE estimated tractor and combine repair and maintenance costs to actual repair and maintenance costs of selected farms. 1989; ASAE Paper No. 89-1024. St. Joseph, Mich.: ASAE.

Knoub Bacht GM, Ahmadi H, Akram A, Karimi M, Repair and maintenance cost model for MF285 tractor: A case study in central region

of Iran. American- American-Eurasian J of Agric and Environ Sci. 2008;4:76-80.
Lazzari M, Mazzetto F, Chapter 3: Analisi economica delle macchine agricole (Economical analisys of agricultural machines). In Prontuario di meccanica agraria e meccanizzazione (Agricultural mechanic and mechanization handbook). Reda ed. Torino; 2009.
Mao Z, Wei Q, Zhang Q, Power efficiency analysis of combine harvester in field operation. Paper No 071027, ASAE Annual Meeting. St. Joseph, Mich.: ASAE; 2007.
Mazzetto F Calcante A, Come valutare i costi della manutenzione (How to evaluate maintenance costs). Il Contoterzista 2010;3:1-6.
Mazzetto F, Calcante A, Salomoni F, Development and first tests of a farm monitoring system based on a client-server technology. Proc. Precision Agriculture '09. Wageningen, the Netherlands, July 6-8; 2009. pp: 389-96.
Morris J, Estimation of tractor repair and maintenance costs. J of Agric Eng Res 1988;41: 191-200.
Pawlak J, Pellizzi G, Fiala M, Development of agricultural mechanisation to censure a long-term world food supply. General background information and requirements. Proc. of XII Meeting Club of Bologna. Bologna, Italy, November 18-19; 2001. pp. 24-47.
Rotz CA, A standard model for repair costs of agricultural machinery. Applied Eng in Agric 1987;3: 3-9.
Rotz CA, Bowers W, Repair and maintenance cost data for agricultural equipment. 1991; ASAE Paper No 91-1531. St. Joseph, Mich.: ASAE.
Sartori L, Galletto L, Costi di riparazione e manutenzione dei trattori nella Provincia di Padova (Repair and maintenance costs of tractors in the Padua district). Rivista di Ingegneria Agraria 1992;23:81-9.
Srivastava AK, Mahoney WT, West NL, The effect of crop properties on combine performance. Trans ASAE 1990;33:63-72.
Ward SM, McNulty PB, Cunney MB, Repair costs of 2 and 4 WD tractors. Trans ASAE 1985;28:1074-6.