# Coefficients of repair and maintenance costs of self-propelled combine harvesters in Italy

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**Abstract:** Purchasing and maintaining agricultural 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. R&M cost estimation models, calculated as a function of accumulated working hours, are usually developed by ASAE/ASABE for the agricultural situation in the United States, which is considerably different than agricultural context of other countries. So, the goal of this work is to recalculate model parameters according to the Italian situation. For this purpose, data related to 20 self-propelled combine harvesters in Italy were collected. According to the model, which was obtained by interpolating the data through a two-parameter power function (as proposed by the literature), the R&M cost incidence on the list price of Italian self-propelled combine harvesters at 3,000 working hours (estimated life of the machines) was 23.1% as compared with 40.2% calculated through the most recent U.S. model.

**Keywords:** operating costs, agricultural mechanization, machinery management

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## 1 Introduction

Purchasing and maintaining agricultural 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, Anderson, 1988; E. U. FADN, 2007).

As it is known, 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 (i.e. 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

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(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), and 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 self-propelled (SP) combine harvesters, and the current construction technology, the life of these machines is estimated to 3,000 h, ASAE D497.7 (2011). Yet, the estimated life is highly variable for each type of machine because it depends on its use (Cross and Perry, 1996). 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 types of machines and 2) able to extrapolate average behaviors from sufficiently wide samples.

At the methodological level, different models are available for calculating R&M costs. 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, Larson and Chung (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, Larson and Chung (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):

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

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 (h); $RF1$ 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. 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. $RF1$ and $RF2$ parameters proposed by ASAE D497.7 (2011) for SP combine harvesters are equal to 4.000 and 2.100, respectively; the values of Df (in hours, estimated life of machines) is 3,000 h and total life of R&M costs is 40.2%. 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. Obviously, since the R&M costs are strongly influenced by operative conditions which can be specific for individual countries, it would be necessary to adapt the *RF*1 and *RF*2 parameters to specific local situations in order to refine the results of cost calculation methodology (Rotz, 1987; Rotz and Bowers, 1991; Gliem et al., 1989; Wahby and Al-Suhaibani, 2001; Frank, 2003).

The objective of the present work was to collect and analyze real data on the R&M costs of SP combine harvesters working in Italy in order to recalibrate *RF*1 and *RF*2 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 SP combine harvesters in Italian contexts. The local models may be used to carry out accurate economic analysis of agro-mechanical investments. Thus, farmers and contractors can make the better decisions related to farm mechanization planning (for example it is possible to carry out comparison between different extended warranty plans). Indeed, all these aspects are based on the estimated costs of agricultural machine use.

## 2 Materials and methods

The present study compiled data on the R&M costs (ordinary and extraordinary) of SP combine harvesters belonging to farmers and contractors working in Italy. The research considered 20 SP combine harvesters of several brands (Italian and foreign) (10 straw walker combines and 10 axial flow combines) with engine power ranging from 159 to 368 kW. Considered machines 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 1. The mean age of the sampled machines was 9 yr (minimum, 2 yr; maximum, 19 yr), and the mean annual use is 367 h yr$^{-1}$ (minimum, 197 h yr$^{-1}$; maximum, 833 h per year). This value is clearly lesser than the U.S. average: because no data are available in literature, we carried out a survey in collaboration with two of the most important farm equipment manufacturers at international level (CNH and John Deere). Results indicated about 500-600 h yr$^{-1}$ as mean annual use of SP combines in U.S. operating conditions.

**Table 1 Characteristics of the considered population of SP combines**

| Number of SP combines | | Power/kW | Working hours/h yr$^{-1}$ | Age/yr |
|---|---|---|---|---|
| 40 | Min. | 151 | 197 | 2 |
| | Max. | 368 | 833 | 19 |
| | Ave. | 236 | 367 | 9 |

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 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 SP combines' owners and, in the absence of such information, from the reported information on the use and maintenance manuals of each single machine (Wertz et al., 1990). The cost of labor for ordinary maintenance was estimated to be 35 € h$^{-1}$ (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-dimensional chart. Interpolation of values performed through the two-parameter power function (1) allowed us to calculate *RF*1 and *RF*2 parameters for SP combine harvesters working in Italy. Since the aim of this study is to verify how the real R&M data, related to a consistent number of machines used in the operating conditions of Italy, fit the well-known power model normally used in the international literature, the statistical analysis here applied is based on a simple regression analysis to such a model and on the related coefficient of determination for evaluating the quality of the power-equation parameters thus obtained.

## 3 Results and discussion

Table 2 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.

**Table 2 Variability of labor, spare parts accumulated working hours and R&M costs of the considered SP combines**

| | Labor /€ | Spare parts /€ | Accumulated working hours/h | Accumulated R&M costs/€ |
|---|---|---|---|---|
| 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% |

Indeed, 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 44%. 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; c) the intensity and modality of use of a single machine; 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 1a highlights the part that required more extraordinary maintenance interventions for SP combines. For these machines, the part most subject to problems was the header unit (49.3% of total interventions), followed by the threshing system and the engine (12.5%), the hydraulics (8.2%) and the classic wear and tear parts (feeder conveyor, 7.6%; grain tank unloading auger, 6.9%). Analyzing the economical incidence (expressed as repair mean cost for each single part) of several parts subject to failure or repair (Figure 1b), it is possible to observe that the transmission represents 32.1%, the header unit represents 20.8%, and leveling system represents 12.2% of the total costs. Thus, certain components break with low frequency (for example, both transmission and leveling represents only 1.3% of the total costs; Figure 2). However, when these parts break, they are expensive to repair. Header unit is, in any case, the part of a SP combine most likely to break down.

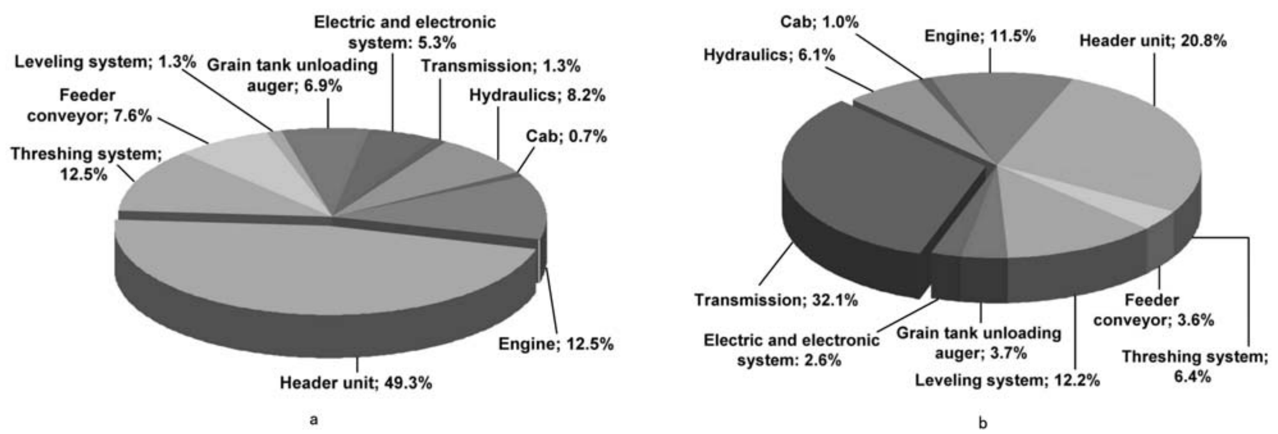


Figure 1(a) Distribution of extraordinary maintenance events as a function of the considered agricultural machine parts and (b) based on the mean cost per single parts

To estimate the *RF*1 and *RF*2 parameters, 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 Equation (2) presents $R^2$ = 0.80, *RF*1 = 4.095 and *RF*2 = 1.591.

$$Crm = 4.095 \cdot \left(\frac{h}{1000}\right)^{1.591} \qquad (2)$$

Clearly, this Equation (2) is 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) 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 with an engine load close to its maximum could accentuate wear phenomena.

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 SP combines compared with the ASAE D497.7 (2011) model is highlighted in Figure 2.

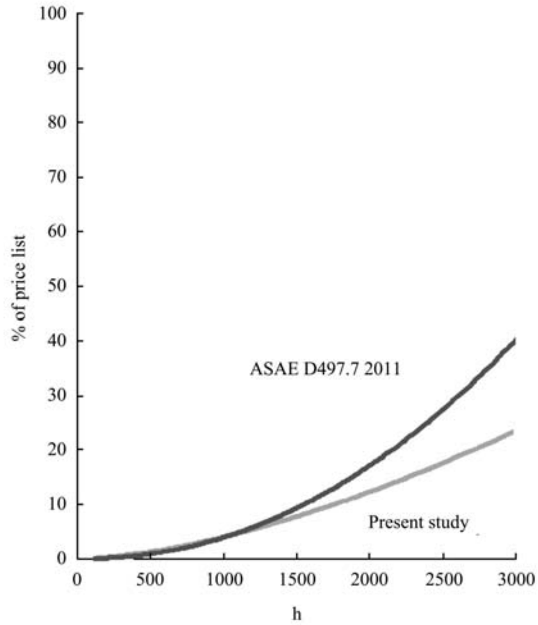


Figure 2 Comparison between our model (Present study) for SP combine harvesters and that proposed by ASAE D497.7 (2011)

The R&M costs in Italy are lesser than those in the U.S.: in fact, considering Df = 3,000 h, 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%. Considering an average list price of a 236 kW SP combine (average engine power of the considered population) equal to €200,000, at 3,000 working hours the estimated R&M costs amount at €80,400 and €46,200 using the *RF*1 and *RF*2 calculated for the U.S and for Italian situation, respectively. The differences of results obtained by the two models are not negligible. In particular, note that the two curves practically show similar trends until 1,200 h (for young machines, the R&M costs are practically the same for both countries). After this value, the U.S. model highlights a greater incidence of *Crm* than the Italian ones probably due to the different intensity of use of the machines (over 500 vs. 367 h $yr^{-1}$) and to the different operating conditions in the two countries. Further, it is important to note that *RF*1 and *RF*2 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).

Finally, Figure 3 shows the R&M cost trend divided as a function of SP combines' typology (axial flow combines vs. straw walker combines).

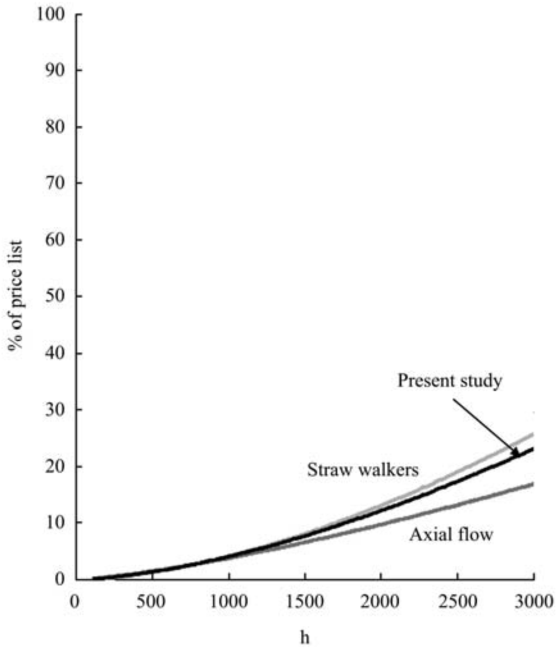


Figure 3 R&M cost model divided as a function of SP combines typology

In this analysis, R&M costs of axial flow combines are lesser than straw walker combines (-9.3% at 3000 working hours). This is probably due to the less number of moving parts (i.e. pulleys, drive belts etc.) in the axial flow models; consequently, the probability of breakages for these machines is lesser compared with the more complicated (from the mechanical point of view, Pessina and Facchinetti, 2011) straw walker combines.

In conclusion, the differences between the ASAE D 497.7 (2011) model and the one calculated for the considered agricultural machines operating in the Italian context are evident. This confirms the need to recalibrate *RF*1 and *RF*2 parameters for local conditions, in order to provide a useful tool for selecting the right time for SP combines replacement, both for contractors (who tend to replace their machines more frequently than farmers) and for farmers who often retain and maintain dated and uneconomic SP combines in their fleet of agricultural machines.

## 4 Conclusions

The goal of this study was to adapt the classical R&M cost model for SP combine harvesters to Italian operating conditions by modifying equation parameters on the basis of R&M costs of 20 SP combines (10 straw walker combines and 10 axial flow combines). Data on ordinary and extraordinary maintenance interventions were collected through direct contact with 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 SP combine harvesters shows that, for a total life of 3,000 h, R&M costs (expressed as a percentage of the list price) are 23.1% as compared with 40.2% calculated through the most recent U.S. model. 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: nowadays, in fact, some 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; Steinberger et al., 2009; Sorensen and Bochtis, 2010). 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.

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