DEFINITION OF REFERENCE MODELS FOR FUNCTIONAL PARAMETERS AND PRICE FOR COMBINE HARVESTERS

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ABSTRACT

Operational and functional parameters of agricultural machines have essential importance and direct influence on farm fleet definition or optimisation (both for tractors and implements), machinery planning and management. Decision support systems and models have been developed in the past mainly analysing and quantifying farm costs while information lack existing correlation with functional parameters such as weight, power, efficiency, etc. Conversely, such parameters play an important role, not only with direct and indirect costs but also with agronomic and environmental performances. Such aspects are highly essential and to some extent critical for capital intensive machines such as combine harvesters.

In the current research the functional parameters of combine harvesters have been analysed (power, weight and tank capacity) providing linear models for the variables which exhibit the highest predictive potential. Highest correlation exhibited power of the machine in a relation with price (r = 0.91) and tank capacity (r = 0.90), which allows to perform forecast analyses related to the evaluation and prediction of costs and performances, thus contributing to the optimisation of the fleet selection process and investments.

Keywords*:* combine harvester, functional parameter, reference model, fleet management, statistical analyses.

1. INTRODUCTION

Management of agricultural systems, machinery and operations rely on complete understanding of operational functions, parameters, and processes. Coordination of planning, decision making and application of determined solutions are based on specifications of the farm and crop with the purpose to meet operation performance requirements and expected profit (Peart & Shoup, 2004). Agriculture, like every business, is supposed to be profitable. An economic evaluation of facilities and justification of preferences related to the investments based on the actual needs create the logical background for adjustment of the best profitable management approach.

Agriculture management is based on composite interaction of available data and resources. Identification of optimal synergy is very complex due to the machinery system combination with agronomic, biological and climatic features (Kaspar et al., 2003; Søgaard & Sørensen, 2004). Complete understanding and consideration of each parameter within the boundaries of the actual needs, their interaction effect on the other parameters and the outcome of the operation might increase the potential of performance, ensure sustainable production and profit.

Continuously advancements in the technology on the farm, in processing, and in agribusiness lead to the development of farm management tools and systems for ensuring successful performance of agricultural operations and machines (Kortenbruck et al., 2016; Peart & Shoup, 2004; Vougioukas et al., 2011). At the same time, intensification of farm practices, saturation of machinery construction, specifications and features lead to more complex decision-making phase, machinery selection process and adjustment of innovative solutions. The adoption of management strategies for enhancement of the efficiencies applied in mechanisation system lead to the modification of cost structure and price policy, impacting decision-making regarding fleet accomplishment and machinery. To predict those impacts and to forecast outcomes of decision alternatives modern agricultural management challenges to a problem-solving framework utilising mathematical models and computer software packages, simulations, spread sheets, linear and non-linear programming, scheduling routines, etc. (Bulgakov et al., 2015; Camarena et al., 2004; Kaspar et al., 2003; Pezzuolo et al., 2014; Rodias et al., 2017; Sopegno et al., 2016). Eventually, all these models and methods are called to simplify and support farms with the most sensitive and requested issues related to the fleet, farm organisation and overall crop production, however, diversity and complexity of available systems not always meet the needs and expectations of real farms (Sopegno et al., 2016). However, machinery management approaches and application diversity available in the market lack the possible correlation of technical parameters of the machines and their economic prerequisites, relations and consequences. Additionally, most of the methods are limited to the research level or applied in the restricted number of experimental farms. While, identification of parameters' performance criteria and their relation to the operation, and evaluation of correlations might create a fundamental base for justification of relatively high investments, operation cost definition and environmental protection. Optimisation of costs and maximisation of efficiencies have primary importance for modern farm management, and it is more obvious and critical in the case of harvesting operation with large capital-intensive investment on the harvesting machines.

Current research is aimed to analyse functional parameters (power, weight and tank capacity) of combine harvesters, to define the impacts of technical and design parameters, to provide linear regression models for the variables which exhibit the highest predictive potential, thus contributing to the optimisation of the fleet selection process, evaluation and prediction of costs and performances.

2. MATERIALS AND METHODS

Combine harvesters are complex agricultural machines intended for crop harvesting operation and designed for three crop processing modules: threshing, separation and cleaning processes (De Baerdemaeker & Saeys, 2013; Hermann, 2018). The threshing system consists of a transverse (conventional) or longitudinal rotor (axial) with threshing elements to separate the grain kernels from the heads, stems or pods. The conventional harvesting machines have a transverse threshing rotor and a straw walker for separation, the axial combination has one or two parallel rotors with threshing elements in front and separation in the rear end, and the hybrid construction of the combines has a transverse threshing rotor and a longitudinal separation rotor. In the modern combine harvesters, the threshing and separation systems are designed as one coherent system. The performance of combine harvester is characterised by grain loss and damage, cleanliness and straw quality. Enhancement of combine harvester's performance is considered as a complex optimisation issue due to a large number of parameters and interdependencies, which may have nonlinear correlations and be even conflicting (Hermann, 2018).

The current study is based on the analyses of 120 models of combine harvesters available in the modern agricultural machinery market intended to harvest a different kind of grain crops. Dataset consists of the variation of combines with conventional, axial and hybrid threshing systems equipped for hillside harvesting with and without a self-levelling control system. For a definition of the most correlated functional parameters of harvesting combines and their influence on the performance of the machine and price, data were analysed with the application of Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) software. Power, weight, tank capacity and list price of the machines, according to the market, were investigated as main variables for applied statistical analyses (Table 1).

Table 1. The range for minimum and maximum values of the considered variables according to the dataset

Variable	Value
Power, kW	110 - 480
Tank capacity, L	4200 - 14500
Weight, kg	7600 - 19500
Price VAT excl., k€	130 - 595
Weight power index, kg kW^{-1}	35.7 – 87.0

Dependencies between considered variables were studied with the application of linear regression analyses. The relevance of the models was quantified by means of correlation studies and dependences modelled according to the linear characteristic equation:

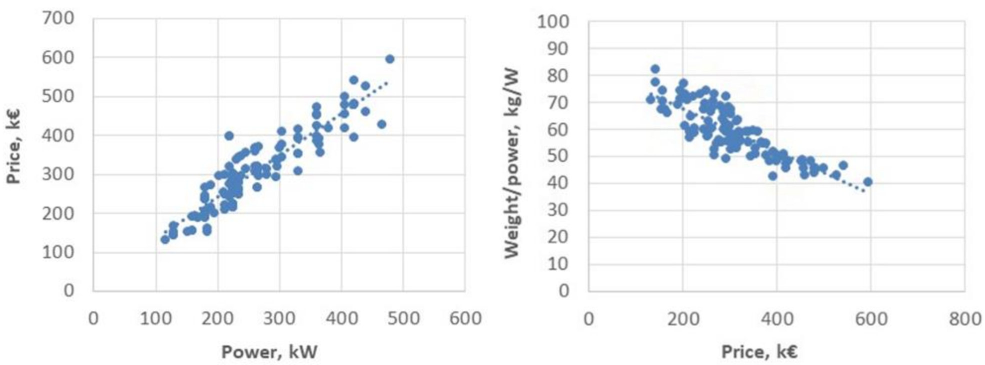
$$y = m_1 \cdot x + q \quad (1)$$

where *x* and *y* represent respectively independent and dependent variables, *mi* is the slope (or linear coefficient) related to the *i*-th independent variables, *q* is the intercept between *y* and *x* variables.

According to the linear regression analysis data reported regarding Pearson correlation coefficient *r*, slope *m* and intercept *q* of the linear models. The simplicity of linear models allows their wide application and consideration by interested parties (farmers, farm management applications and agencies, authorities, etc.) for justification of machines parameters' requirements and forecasting. The liner models considered as not large models that provide a high degree of detail and precision, nevertheless, the models are based on the defined functional parameters and represent robust and realistic output, provide sufficient details for decision making and selection optimisation.

3. Results

Data collected for the 120 models were statistically analysed as discussed above. A graphical representation as reported in Figure 1 already gives evidence of existing correlations between variables, in general acceptably approximable through linear trends. In particular, high linearity can be recognised between power, weight and price, as also evidenced by the following analyses.



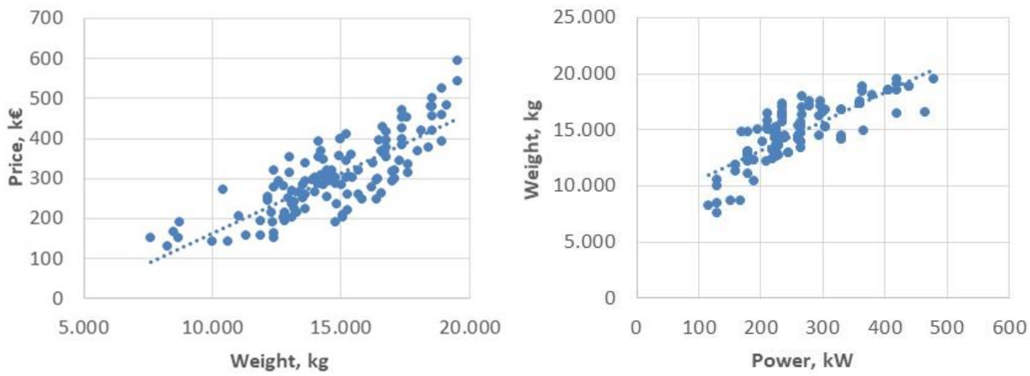


Figure 1. Graphical representation of most interesting correlation between studied variables

The linear modelling and correlation analysis for combine harvesters exhibited relatively high Pearson coefficients between all considered variables. The highest correlation was found between price and power (r = 0.91), as well as between power and tank capacity (r = 0.90). Slightly lower values could be recognised between weight and tank capacity (r = 0.8), and between price and weight (r = 0.81), as reported in Table 2.

Compared to previously published linear regression analyses performed on seeding machines (Tatevik et al., 2018) and sprayers (Yezekyan et al., 2018), combine harvesters models exhibit in general higher correlation between performance parameters. This can be probably explained as a consequence of the lower number of companies that compete in the market: such condition most probably reduces competitiveness and increases homogenization of performances and constructive principles.

Table 2. Correlation matrix of Pearson coefficient *r* for functional parameters of combine harvesters

	Tank capacity, L	Weight, kg	Power, kW	Price VAT excl.,€
Tank capacity, L	1	0.8023	0.9059	0.8220
Weight, kg		1	0.8212	0.8084
Power, kW			1	0.9102
Price VAT excl.,€				1

Linear models were estimated for all the variables' combinations according to the linear regression analysis. Results are summarised in Table 3. For combine harvesters, it can be noticed how for each additional tonne of the machine, a power supply of 26 kW has to be counted, while for the same weight, a volume of tank capacity of about 0.66 cubic meter has to be taken into account. With regard to needed investment, an average price of 1070 € has to be considered for each kW of power. The same table reports coefficients of determination R^2 and standard errors for the same models. Dealing with linear models, coefficients of determination are clearly in agreement with Pearson coefficients. Standard errors are in general relatively low, with higher uncertainty levels especially in the case of linear regressions based on weight. However, in particular, in the case of high power/high weight machinery, the models provide good forecasting results.

Table 3. Correlation matrix of Pearson coefficient *r* for functional parameters of combine harvesters

	Price	ε	R^2
Power	$P = 0.0008 \cdot Pr + 23.11$	33.9	0.8285
Weight	$M = 0.0216 \cdot Pr + 8120$	1510	0.6535
Capacity	$C = 0.0181 \cdot Pr + 3686$	1203	0.6757
	Power	**ε**	**R^2**
Weight	$M = 25.85 \cdot P + 8023.$	1467	0.6744
Capacity	$C = 23.39 \cdot P + 3128$	895	0.8207
Price	$Pr = 1070 \cdot P + 27970$	39500	0.8285
	Weight	**ε**	**R^2**
Power	$P = 0.0261 \cdot M - 124.3$	46.5	0.6744
Capacity	$C = 0.6579 \cdot M - 485.57$	1256	0.6436
Price	$Pr = 30.19 \cdot M - 138590$	56390	0.6535
	Capacity	**ε**	**R^2**
Weight	$M = 0.9782 \cdot C + 5740$	1531	0.6436
Power	$P = 0.0351 \cdot C - 62.92$	34.5	0.8207
Price	$Pr = 37.43 \cdot C - 38270$	54540	0.6757

For different groups of machines: *C*: tank capacity (L); *M*: weight (kg); *P*: power (kW); *L*: working width (m); *Pr*: estimated price (€)

4. DISCUSSION AND CONCLUSIONS

Many farm management solutions provide the transition of collected information into knowledge. However, there is an actual strategic issue in the model building, to develop generalised and sufficient predictive model with simple and robust forecasting abilities. Modelling approach needs to meet actual needs raised from required interests and meet the expectations of applicants. From the current point of view, developed linear models for combine harvesters allow making simplified calculations of main technical requirements related to the machine power, weight and capacity. The latest allows having a better overview of the farm organisation, operation management and performance prediction, and to have a better arrangement of work, timeliness and independence in scheduling individual operations. According to the performed analyses the highest impact on the price formation exhibited the power of the machine, thus initial forecast of the combine harvester investment needs to consider 30 k€ and increasing by 1100 euro for each kW of the harvesting equipment. Additionally, considering the corresponding correlation of capacity of 0.35 m^3 and weight of 26 kg per each kW.

The linear construction of the models here reported allows further implementation and combination with farm management systems and decision-making approaches as initial data for functional parameters definition and price prediction. Furthermore, price forecasting and definition of initial investment might allow the parties involved arrive at the economically practical decision of operation management definition related to the machine purchase, rent or leasing, which is crucial in the case of self-propelled harvesting equipment, which requires huge investment and has comparatively very high prices in the market.

REFERENCES

Bulgakov, V., Adamchuk, V., Arak, M., & Olt, J. (2015). Mathematical Modelling of the Process of Renewal of the Fleet of Combine Harvesters. Agriculture and Agricultural Science Procedia. https://doi.org/10.1016/j.aaspro.2015.12.027

Camarena, E. A., Gracia, C., & Cabrera Sixto, J. M. (2004). A Mixed Integer Linear Programming Machinery Selection Model for Multifarm Systems. Biosystems Engineering, 87(2), 145–154. https://doi.org/10.1016/j.biosystemseng.2003.10.003

De Baerdemaeker, J., & Saeys, W. (2013). Advanced control of combine harvesters. IFAC Proceedings Volumes (IFAC-PapersOnline). https://doi.org/10.3182/20130828-2-SF-3019.00069

Hermann, D. (2018). Optimisation of Combine Harvesters using Model-based Control. In DTU Elektro.

Kaspar, T. C., Colvin, T. S., Jaynes, D. B., Karlen, D. L., James, D. E., Meek, D. W., … Butler, H. (2003). Relationship between six years of corn yields and terrain attributes. Precision Agriculture. https://doi.org/10.1023/A:1021867123125

Kortenbruck, D., Sapounas, A. A., Griepentrog, H. W., Paraforos, D. S., Ziogas, V., Vassiliadis, V., & Stamkopoulos, K. (2016). A Farm Management Information System Using Future Internet Technologies. IFAC-PapersOnLine. https://doi.org/10.1016/j.ifacol.2016.10.060

Peart, R. M., & Shoup, W. D. (2004). Agricultural Systems Management Ontimizing Efficiency and Performance. Marcel Dekker Inc., New York, pp. 280

Pezzuolo, A., Basso, B., Marinello, F., & Sartori, L. (2014). Using SALUS model for medium and long term simulations of energy efficiency in different tillage systems. Applied Mathematical Sciences. https://doi.org/10.12988/ams.2014.46447

Rodias, E., Berruto, R., Bochtis, D., Busato, P., & Sopegno, A. (2017). A computational tool for comparative energy cost analysis of multiple-crop production systems. Energies. https://doi.org/10.3390/en10070831

Søgaard, H. T., & Sørensen, C. G. (2004). A model for optimal selection of machinery sizes within the farm machinery system. Biosystems Engineering, 89(1), 13–28. https://doi.org/10.1016/j.biosystemseng.2004.05.004

Sopegno, A., Busato, P., Berruto, R., & Romanelli, T. L. (2016). A cost prediction model for machine operation in multi-field production systems. Scientia Agricola. https://doi.org/10.1590/0103-9016-2015-0304

Sørensen, C. A. G., Milan, M., Bochtis, D., Tieppo, R. C., & Romanelli, T. L. (2018). Modeling cost and energy demand in agricultural machinery fleets for soybean and maize cultivated using a no-tillage system. Computers and Electronics in Agriculture. https://doi.org/10.1016/j.compag.2018.11.032

Vougioukas, S. G., Bochtis, D. D., Sørensen, C. G., Suomi, P., & Pesonen, L. (2011). Functional requirements for a future farm management information system. Computers and Electronics in Agriculture. https://doi.org/10.1016/j.compag.2011.02.005

Yezekyan, T., Marinello, F., Armentano, G., & Sartori, L. (2018). Analysis of cost and performances of agricultural machinery: Reference model for sprayers. Agronomy Research. https://doi.org/10.15159/AR.18.049

Yezekyan, Tatevik, Marinello, F., Armentano, G., Trestini, S., & Sartori, L. (2018). Definition of Reference Models for Power, Weight, Working Width, and Price for Seeding Machines. Agriculture. https://doi.org/10.3390/agriculture8120186