

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

## A web mobile application for agricultural machinery cost analysis

**This is a pre print version of the following article:**

*Original Citation:*

*Availability:*

This version is available <http://hdl.handle.net/2318/1619052> since 2017-05-16T15:29:58Z

*Published version:*

DOI:10.1016/j.compag.2016.08.017

*Terms of use:*

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)

This Accepted Author Manuscript (AAM) is copyrighted and published by Elsevier. It is posted here by agreement between Elsevier and the University of Turin. Changes resulting from the publishing process - such as editing, corrections, structural formatting, and other quality control mechanisms - may not be reflected in this version of the text. The definitive version of the text was subsequently published in COMPUTERS AND ELECTRONICS IN AGRICULTURE, 130, 2016, 10.1016/j.compag.2016.08.017.

You may download, copy and otherwise use the AAM for non-commercial purposes provided that your license is limited by the following restrictions:

- (1) You may use this AAM for non-commercial purposes only under the terms of the CC-BY-NC-ND license.
- (2) The integrity of the work and identification of the author, copyright owner, and publisher must be preserved in any copy.
- (3) You must attribute this AAM in the following format: Creative Commons BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/deed.en>), 10.1016/j.compag.2016.08.017

The publisher's version is available at:

<http://linkinghub.elsevier.com/retrieve/pii/S0168169916306597>

When citing, please refer to the published version.

Link to this full text:

<http://hdl.handle.net/>

# A WEB MOBILE APPLICATION FOR AGRICULTURAL MACHINERY COST ANALYSIS

Alessandro Sopegno<sup>1</sup>, Angela Calvo<sup>1</sup>, Remigio Berruto<sup>1,\*</sup>, Patrizia Busato<sup>1</sup>, Dionysis Bocthis<sup>2</sup>

<sup>1</sup>Università degli Studi di Torino, Dipartimento di Scienze Agrarie, Forestali e Alimentari (DISAFA), Grugliasco, Italy

<sup>2</sup> Department of Engineering, Aarhus University, Inge Lehmanns Gade 10, 8000 Aarhus C, Denmark

\* e-mail of corresponding author: [remigio.berruto@unito.it](mailto:remigio.berruto@unito.it)

## Abstract:

It has been demonstrated that machinery and equipment are major cost items in farm businesses in different countries. Moreover, in the last years, high power machines, advanced technologies, higher prices for spare parts and repairing process, and fuel consumption contributed to an even more rising of the machinery costs. Many engineering and economic methods have been implemented to calculate machinery use and cost, but they are almost confined in scientific and technical documentations making it difficult for a farmer to apply these methodologies for deciding on buying, leasing, or sharing agricultural machinery.

Information and communications technology (ICT) has an increasingly important role on business processes and provides a powerful foundation to address many daily problems. Today users want to be connected to useful information in real time. To that effect, the aim of this work was to develop an easy-to-use mobile application, called “AMACA” (Agricultural Machine App Cost Analysis) for determining the machinery cost in different field operations and making it available via a web mobile application using a cross-platform approach. The customer-driven Quality Function Deployment [QFD] approach was implemented in order to link the user expectations with the design characteristics of the app. The AMACA app is free, readily available, and does not require

24 any installation on the end users' devices. It is a cross-platform application meaning that it operates  
25 on any device through a web interface and major browsers support it. The user can make  
26 subsequent calculations of the sensitivity of the results by varying the input parameters (fuel price,  
27 interest rate, field capacity, tractor power, etc.) and compare the results. AMACA app can support  
28 the decisions on whether to purchase a new equipment/tractor (strategic level), the use of own  
29 machinery or to hire a service, and also to select the economical appropriate cultivation system  
30 (tactical level).

31 .

32

33 **Keywords:** Agricultural machinery cost, machinery management, agricultural operations

34

## 35 **1 INTRODUCTION**

36 Information and communications technology (ICT) has an increasingly important role on business  
37 processes and provides a powerful foundation to address many daily problems. Today users want to  
38 be connected to useful information in real time. For this reason the use of mobile technology has  
39 grown rapidly; in fact, for the year 2014 mobile technology and applications were identified in the  
40 top 10 strategic technology trends globally (Gartner, 2014).

41 Nevertheless, in the agricultural sector there is a slow adoption in the use of mobile technology, if it  
42 is compared to other business domains (Xin et al., 2015). This is in contrast with the huge potential  
43 for applied mobile technologies in the sector for a various number of decision making processes  
44 including tailored weather information, geo-referenced soil maps, natural disasters forecast,  
45 extension service advices, distance learning modules, plant diseases diagnosis, agri-products  
46 traceability, economic information, and agricultural machinery management (Xin et al., 2015).

47 It has been demonstrated that machinery and equipment are major cost items in farm businesses in  
48 different countries (Bochtis et al., 2014). Moreover, in the last years, high power machines,  
49 advanced technologies, higher prices for spare parts, repairing process and fuel consumption  
50 contributed to an even more rising of these costs. Actually, the cost of machinery remains a  
51 significant portion of the cost of production of a farm for many operations and continues to be one  
52 of the highest input costs for farmers (Buckmaster, 2003). Anderson (1988) showed that the  
53 machinery costs are about 35-50% of the farm cost. Many engineering and economic methods have  
54 been implemented to calculate machinery use and cost, but they are almost confined in scientific  
55 and technical documentations making it difficult for a farmer to apply these methodologies for  
56 deciding on buying, leasing, or sharing agricultural machinery.

57 Agricultural machinery cost regards two types of cost, namely the annual ownership (or fixed) cost,  
58 which occurred regardless of the machine use, and the operating (or variable) cost which is directly  
59 connected to the machine use intensity. The former cost derives from depreciation, interest,  
60 housing, and insurance cost, while the latter derives from maintenance, repair, fuel and lubricant  
61 consumption, labor cost and depends on various factors including hours of annual use, type of  
62 performed operation, field size and characteristic, operator's skills and experience, timeliness etc.  
63 (Schuler and Frank, 1991). There is not a unique process to determine machine costs and the most  
64 accurate method to evaluate them is the complete records of the actual costs incurred: unfortunately  
65 this method is not usable for prompt forecast purposes. The possibility to know in advance such  
66 costs is strategic for the farmers, but the agricultural machine cost determination available by  
67 internet applications e.g. (Busato and Berruto, 2014) are lacking of a mobile app.

68 The aim of this work was to develop an easy-to-use mobile application (app), namely Agricultural  
69 Machine App Cost Analysis (AMACA) for determining the machinery costs in different field  
70 operations and makes it available via a web mobile application using a cross-platform approach.  
71 Mobile apps in agriculture can be clustered in two broad categories (Brugger, 2011): m-learning

72 (transfer of know-how on specific farming techniques and trends) and m-farming (decision support  
73 systems and services based on localized-specific data); for its characteristics AMACA can be  
74 considered an m-farming app.

## 75 **2 MATERIALS AND METHODS**

### 76 **2.1 The design process**

77 The design process for the AMACA development was focused on extracting the specific  
78 requirements for farm operations cost prediction including the steps of extracting the individual  
79 users' requirements, identifying the necessary system components, and identifying the need for  
80 supplemental development. The methodology of quality function deployment (QFD) has been  
81 followed in this process. QFD is one of the most common customer-driven tools of total quality  
82 management process linking the user expectations with the design characteristics of the product  
83 (Carnevalli and Miguel, 2008; Chan and Wu, 2002). Although QFD has been considered as a  
84 having a high potential for the design of new systems, especially in the case of ICT (Schiefer,  
85 1999), there is a limited number of design process that have implemented such a methodology in  
86 the agricultural domain (Sørensen et al., 2010).

87

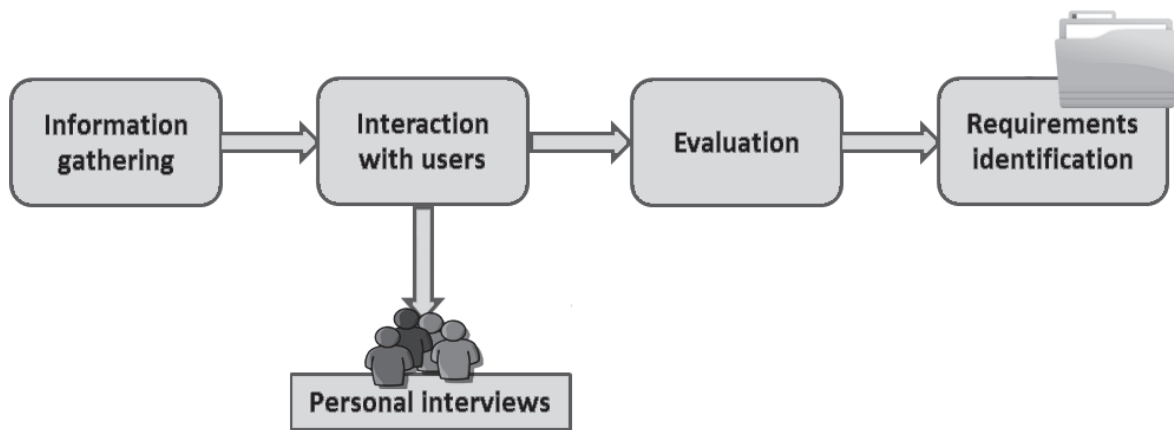


Figure 1 - Identification of user needs

88

89

90

91 The general steps of the QFD include the following:

92 - Users identification

93 - Users requirements extraction

94 - Users requirements prioritization

95 - Design parameters identification

96 - Determination of relationships between users requirements and design parameters

97 - Correlation between design parameters

98 The above mentioned steps are described in detail in the following sections.

99

### 100 2.1.1 Users requirements

101 The identification of the users requirements includes four phases (Figure 1): the information  
 102 gathering where the target groups of the users are identified and the questionnaires are defined, the  
 103 interaction with the users where personal interviews take place, the evaluation phase where the user  
 104 needs are addressed, and the requirements identification phase where the various requirements are  
 105 prioritized according to the users preferences. The methodological approach involved a

106 participatory approach and analysis, extracting current farm management challenges facing  
107 agricultural machinery users and owners.

108 Four target user groups were identified, including:

109

110 a. **Farmers.** As users the farmers have different roles. A farmer can use the application on a  
111 strategic level, e.g. to assess the cost for purchasing a new machinery (i.e. tractor,  
112 equipment, self-propelled machine), or in case of owning a machinery she/he can evaluate the  
113 cost for providing services to other farmers (i.e. to act as contractors), or for verifying the  
114 benefit of using a contractor service.

115

116 b. **Contractors.** Similarly to farmers, contractors can assess a number of decisions on strategic  
117 level (e.g. purchase more machines), on tactical level (to e.g. find the break-even point in the  
118 use of machinery), and on operation level (.e.g. to price the rates of servicing).

119

120 c. **Consultants.** Consultants might work for advisory services or private companies to support  
121 farmers in decision making for machinery purchase or contracting a service, and also to  
122 support farmers to evaluate the whole production cost for a crop.

123

124 d. **Machinery dealers.** Machinery dealers can use the application for providing farmers with  
125 an optimal solution for purchasing machinery based on their individual needs.

126

127 A number of user requirements for agricultural fleet management systems have been identified in  
128 Sørensen & Bochtis (2010). The majority of these user requirements have been adopted and/or



129 modified while a number of them targeted to the application requirements were also identified. The  
 130 voiced user requirements for the development of the AMACA app are listed in Table 1.

131

132 **Table 1 – Voiced user requirements for n agricultural management system**

<b>General category</b>	<b>ID</b>	<b>Specific requirement</b>
Data aquisition	R1.1	Improved general knowledge of the production process
	R1.2	Effective documentation system
	R1.3	Detailed work time specification
	R1.4	Detailed cost elemets specification
	R1.5	Information search availability (quick access to information)
	R1.6	Easy and quick access to information
	R1.7	Data exchange interfaces
	R1.8	Available data bases
	R1.9	Reduction of user inputted errors
Decision making	R2.1	Resource optimization (e.g., labor, fuel)
	R2.2	Generation of tasks orders
	R2.3	Environmental benefits (e.g., soil compaction, resource usage)
	R2.4	Preventive maintenance
	R2.5	Benchmarking
Software / hardware / technology components	R3.1	Dedicated user-interface
	R3.2	Application roughness
	R3.3	Communication with internal databases

---

R3.4 Communication with external databases

R3.5 Availability in various devices

---

133

134 A five-point scale measure was implemented for ranking the requirements which was defined  
 135 according to the following mapping:

136 1 → not at all important,

137 2 → not very important,

138 3 → fairly important,

139 4 → very important, and

140 5 → extremely important

141 For the extraction of the average relative importance ratings of the identified requirements the  
 142 simple isobaric method was implemented.

143

144

### 145 **2.1.2 Identification of design parameters**

146 The process of design parameters identification for the AMACA app was based on the results from  
 147 a workshop where various technical experts were involved. After the initial identification the design  
 148 parameters were grouped in six representative categories. The selected design parameters are listed  
 149 in Table 2.

150

151 **Table 2 - Selected design parameters grouped within six main categories.**

---

Category	Description	ID	Design parameters
----------	-------------	----	-------------------

---

Usability	The usability of the application regards the level of convenience that the user navigates and getting familiar with the app with a minimum amount of potential errors. It also refers to the level that the app enables user to read and internalize information.	F1.1	Step-by-step functions
		F1.2	Tutorial
		F1.3	Low maximum number of steps (e.g. 3)
		F1.4	Self-explanatory navigation labels
		F1.5	Large site-wide buttons
		F1.6	Reduced pop-out menu
		F1.7	Use of input values ranges (thresholds)
		F1.8	Information button
		F1.9	Skimmable text presenting only the necessary information.
Presentation	Presentation refers to the visual appearance and organization of the user interface and of the provided information.	F2.1	Simple and minimalistic design
		F2.2	Touch friendly interface (e.g. line spacing)
		F2.3	Text should be readable on any size of monitor (Fit screen resolution)
Visualization	Visualization regards the input and output processes	F3.1	Pop-up menus for input selection

and has to do with the analytical features that are used for inserting the information and presenting the results

F3.2

Dashboards practices in the results presentation, such as tables and charts

---

Personalization

Personalization regards the customization for different user profiles in order to cover the needs of experienced and especially inexperienced users

F4.1

Different user profiles (Farmers, Contractors, Administrator)

F4.2

Multi-language menus

---

Interoperability

Interoperability with data sources and other applications

F5.1

Software interoperability (e.g. Adroid, IOS, Windows)

F5.2

Hardware interoperability: Wireless communication and Bluetooth

F5.3

No instalation need

Expandability for additional functions

F6.1

Use of open source encoding

Scalability

---

152

153 **2.1.3 Correlation between the design parameters**

154

155 Each design parameter has to be correlated with each one of the others as the latest step of the QFD  
 156 approach, based on the measure of the correlation degree presented in Table 3:

157 **Table 3 – Measures of correlation degree for the design parameters**

Symbol	Correlation degree
‡	strong positive
+	weak positive
◇	no correlation
∨	weak negative
⊖	strong negative

158

## 159 **2.2 Cost determination**

160 Machinery fixed costs include depreciation, interest of investment, taxes, insurance and housing,  
 161 while variable costs include repair and maintenance, wages, fuel and lubricants as initially  
 162 suggested by Fairbanks et al. (1971) and now upgraded by ASABE (2009).

### 163 **2.2.1 Fixed cost**

164 For the estimation of the fixed cost it is assumed that the machines are used up to their maximum  
 165 number of operating hours, called estimated life. The estimated life  $h_{tot}$  used in the AMACA app  
 166 was obtained by the (ASABE, 2009). Using afterward the machine annual use ( $h$ ) as input value,  
 167 the estimated life of the machine in years ( $N$ ) is calculated.

168 The fixed cost is calculated both for tractors and equipment and concerned annual costs. The  
 169 estimation of both depreciation and interest cost requires the machine remaining value which is  
 170 provided by the ASABE (2009) formula:

171

$$172 \quad V_r = 100(C_1 - C_2\sqrt{N} - C_3\sqrt{h})^2 \quad (1)$$

173 where  $V_r$  is the machine remaining value (€),  $C_i$  ( $i=1,2,3$ ) are machine dependent coefficients  
 174 (ASABE, 2009),  $N$  are the estimated machine life (y), and  $h$  is the annual use of the machine (h).

175 Depreciation is a cost that is the result of the age, the wear and the obsolescence of a machine. Also  
 176 if the technology and design changes may accelerate the machine obsolescence, however the age  
 177 and accumulated hours of use are the major factor in determining the remaining value of a machine  
 178 (Poozesh et al., 2012). The following formula was implemented in AMACA:

$$179 \quad Q_a = \frac{V_0 - V_r}{N} \quad (2)$$

181 where  $V_0$  is the initial machine value (€)

182 Inflation reduces the real cost of investing capital in farm machinery. The formula which uses an  
 183 average interest rate  $i$  in the  $N$  years of the machine life was considered (Piccarolo et al., 1989):

$$184 \quad Q_i = \frac{V_0 + V_r}{2} \cdot i \quad (3)$$

186 where  $Q_i$  annual interest value and  $I$  is the annual average interest rate.

187 The annual insurance and housing cost are case depended and provided as an input by the user.

### 188 2.2.2 Variable costs

189 Repair and maintenance cost usually represent about 10%-15% of the total mechanization costs  
 190 (Calcante et al., 2013). For the estimation of the repair and maintenance cost the formula proposed  
 191 by the ASABE Standards, (2006) was implemented:

$$192 \quad RM_h = \frac{RF_1 \cdot P \cdot \left(\frac{h_{tot}}{1000}\right)^{RF_2}}{h_{tot}} \quad (4)$$

193 where  $RM_h$  is the hourly repair and maintenance cost (€),  $R_{F1}$  and  $R_{F2}$  are repair and maintenance  
 194 coefficients, machine dependent (ASABE, 2009, Table 3), and  $P$  is the machine list price in (€).

195 Fuel and lubricant cost represent at least 16 - 45% of the total operation costs (Siemens and Bowers,  
 196 1999). Estimation models have been presented in various studies (ASAE, 2002; Grisso et al., 2004;  
 197 Siemens and Bowers, 1999). The fuel consumption formula used by AMACA was obtained by  
 198 Grisso et al. (2004):

199

$$200 \quad Q = (2.64X + 3.91 - 0.203\sqrt{738X + 173}) \cdot X \cdot P_{pto} \quad (5)$$

201 where  $Q$  is the fuel (diesel) consumption at partial load ( $l \text{ h}^{-1}$ ),  $X$  is the ratio of equivalent PTO  
 202 power to rated PTO power, and  $P_{pto}$  is the rated PTO power (kW). Considering that this equation  
 203 model fuel consumption is 15% higher than the field acquisition (Grisso et al., 2004), the same  
 204 reduction was applied for the fuel consumption calculation in AMACA.

205 Lubricants consumption ( $L$ , in  $l \text{ h}^{-1}$ ) is calculated as indicated in ASAE Standard (2009):

$$L = 0.000566 P_{pto} + 0.02487$$

206

207 For the estimation of the labor cost the hourly wage which is provided as an input is considered.  
 208 Also as an input the consumables cost ( $\text{€ ha}^{-1}$ ) is provided by the user.

209 Performance rates for agricultural equipment depend from achievable field speeds and the efficient  
 210 use of time. Field speeds may be limited by heavy yields, rough ground, and adequacy of operator  
 211 control. Small or irregularly shaped fields, heavy yields, and high capacity machines may cause a  
 212 substantial reduction in field efficiency. Typical speeds and field efficiencies are given in Table 3 of  
 213 ASAE Standards, (2009) and AMACA referred to it for parameters range. Both the working speed  
 214 and the tools width were used to calculate the draft force required to the tractor by the equipment to  
 215 accomplish the field operation and to evaluate the operation cost per hectare.

216 The equation of the ASAE Standard (2009) was used to calculate the draft force at the tractor  
 217 drawbar required to pull a specific operating machines for tillage or seeding operations:

$$218 \quad F = S_t \cdot [A + B \cdot S_f + C \cdot S_f^2] \cdot W_m T_d \quad (6)$$

219 where  $F$  is the draft force required at the tractor drawbar (N),  $A$ ,  $B$  and  $C$  are machine specific  
 220 parameters (ASABE, 2009),  $S_t$  is the soil texture (ASABE, 2009),  $S_f$  is the machine field speed (km  
 221  $h^{-1}$ ),  $W_m$  is the machine width (m), and  $T_d$  is the tillage depth (cm).

222

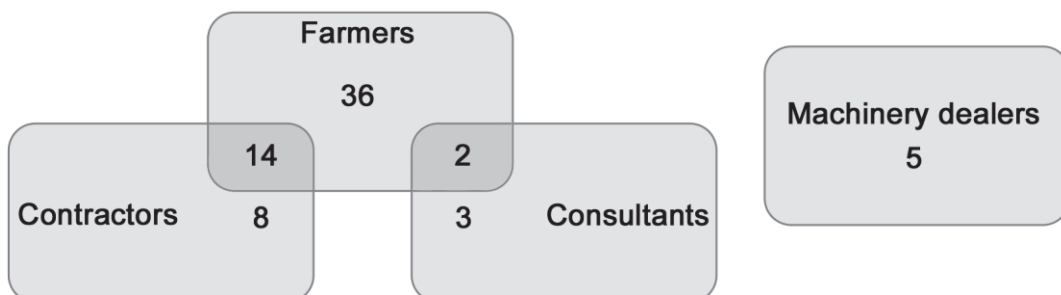
### 223 3 RESULTS AND DISCUSSION

#### 224 3.1 Design process

##### 225 3.1.1 Target groups

226 The study was carried out as an interview survey during the agricultural machinery fairs in February  
 227 and October 2014 in Verona, Italy, and Cremona, Italy, respectively. The requirements gathering  
 228 survey included targeted question through a one-to-one discussion administered by an experienced  
 229 researcher on the agricultural management area.

230



231

232

233

Figure 2 - Distribution of different end user types



234

235 In total 68 people were interviewed. Due to overlaps in some of the users types (Figure 2) the  
236 following categories eventually were considered:

237 Solely farmer: 36

238 Farmer-contractor: 14

239 Solely contractors: 8

240 Consultant-farmer: 2

241 Solely consultant: 3

242 Machinery dealers: 5

243

244

### 245 **3.1.2 Prioritization of user requirements**

246 The user requirements score is presented in Table 4. As a result, the 4 most important rankings are  
247 related to data acquisition and control. Farmers lack in knowledge of standard data on machinery  
248 use and they need some guidance on that. In fact the most important is the user requirement R1.6 –  
249 Easy and quick access to information. Connected to R1.6 there is R3.1 – dedicated user interface  
250 and R3.2 – application roughness. They need simple interface on a device (such as smartphone) that  
251 can be used also in the field or in open spaces. The less important requirement was R3.4 - the  
252 connection to external databases: this fact reflects the fear of the farmers to share their own data  
253 with some agencies database. However, from the scientific point of view external data bases are a  
254 prerequisite for efficient information systems in agriculture, and this will be considered in a next  
255 version of AMACA. Finally, users require to have detailed cost and work time specifications (R1.3,  
256 R1.4) other than to limit possible input errors (R1.9).

257 Figure 3 provides the prioritization of the user requirements.

258

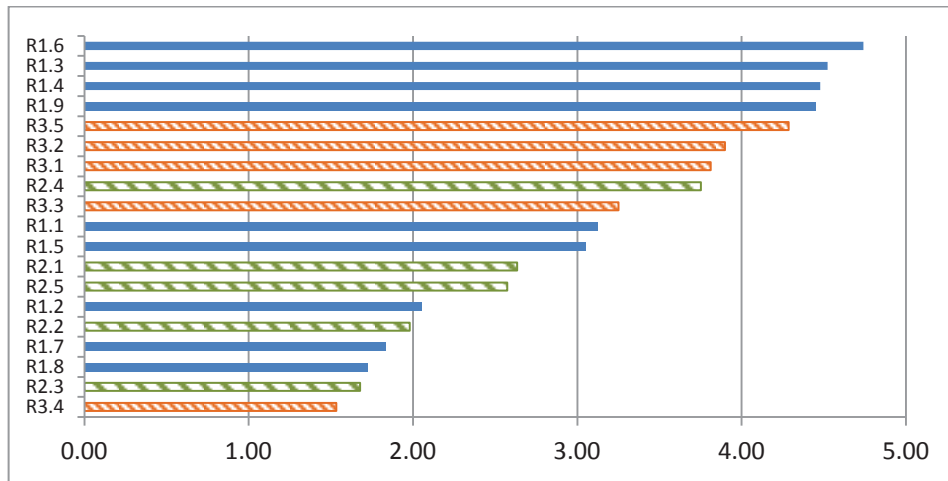
259

**Table 4 – Score on the selected requirements of different users groups**

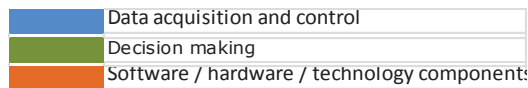
Requirement	Average score	Solely farmer	Farmer contractor	Farmer consultant	Solely contractor	Solely consultant	Machinery dealers
R1.1	3.12	3.11	3.00	4.50	2.13	5.00	1.00
R1.2	2.05	1.22	1.43	2.50	1.75	3.00	2.40
R1.3	4.52	4.19	4.50	4.50	4.88	4.67	4.40
R1.4	4.48	4.33	4.64	4.50	5.00	5.00	3.40
R1.5	3.05	2.11	2.79	3.50	3.25	3.67	3.00
R1.6	4.74	4.75	4.57	4.50	4.63	5.00	5.00
R1.7	1.83	1.11	1.43	1.50	1.63	2.33	3.00
R1.8	1.72	1.14	1.64	1.50	2.00	1.67	2.40
R1.9	4.45	4.42	4.21	4.50	4.50	4.67	4.40
R2.1	2.63	3.94	4.07	2.50	2.63	1.67	1.00
R2.2	1.98	3.17	3.14	2.00	1.38	1.00	1.20
R2.3	1.68	1.50	1.07	2.50	1.00	3.00	1.00
R2.4	3.75	4.53	4.71	4.00	4.88	3.00	1.40
R2.5	2.57	2.00	2.57	3.00	2.88	4.00	1.00
R3.1	3.81	3.50	4.00	3.50	3.88	4.00	4.00
R3.2	3.90	4.89	4.86	3.50	4.75	3.00	2.40
R3.3	3.25	2.31	2.79	3.50	3.25	3.67	4.00

R3.4	1.53	1.67	1.43	2.00	1.38	1.33	1.40
R3.5	4.29	4.22	4.36	4.00	3.88	4.67	4.60

260



261



262

263

Figure 3 - The average raking of the users requirements.

264

265 **3.1.3 Relationship raking**

266 After the summation of the relationships between users requirements the highest values have been  
 267 identified (Figure 4). Specifically, two interoperability design parameters (hardware  
 268 interoperability, 120.97 and no installation need, 120.97), one visualisation (dashboard practices in  
 269 results presentation, 158.08) and one usability (skimmable text for necessary information, 128.13)  
 270 presented the highest values. The lowest values regarded personalisation (different users profile,  
 271 6.39) usability (reduced pop-out menu, 28.71, large site-wide buttons, 55.64 and step by step  
 272 functions, 65.31).

273

	Importance rating	Usability									Presentation			Visualisation		Personalisation		Interoperability			Scalability			
		F1.1	F1.2	F1.3	F1.4	F1.5	F1.6	F1.7	F1.8	F1.9	F2.1	F2.2	F2.3	F3.1	F3.2	F4.1	F4.2	F5.1	F5.2	F5.3	F6.1			
User requirements	Data acquisition and control	R1.1	3.12		9					9	9					1		1						
		R1.2	2.05	1	9						9	9	1	1	1		1		3	1				
		R1.3	4.52							3						9								
		R1.4	4.48													9								
		R1.5	3.05	3		3	9	3	1	9	3	9				3	3		9	1				
		R1.6	4.74	9	9	9	9	9	3	9	3	9	9	9	9	3	1		9	9	3	3		
		R1.7	1.83							9													9	
		R1.8	1.72								3													
		R1.9	4.45	3			1	9	9	9		1	3	9	3	1			3					
	Predictive planning and optimisation	R2.1	2.63							1						3				3				
		R2.2	1.98													1								
		R2.3	1.68													1								
		R2.4	3.75							3						3								
		R2.5	2.57								9		3			9	1			1				
	Software/hardware/technology components	R3.1	3.81	3	1	9	3	1	3	1		3	3	9	9	9	1	1	9	3	1	1	9	
		R3.2	3.90													1					9	9	1	
		R3.3	3.25																	3	9	9	3	
		R3.4	1.53															1		3	9	9	3	
		R3.5	4.29										3	9	9	1	1		1	9	9	9	9	
Raw score		65.31	93.04	86.14	81.58	55.64	28.71	117.91	98.28	128.13	76.74	117.61	117.61	61.98	158.08	6.39	118.01	118.02	120.97	120.97	103.04			
Relative score (%)		3.48%	4.96%	4.60%	4.35%	2.97%	1.53%	6.29%	5.24%	6.84%	4.09%	6.28%	6.28%	3.31%	8.43%	0.34%	6.30%	6.30%	6.45%	6.45%	5.50%			
Ranking		1	2	2	2	1	1	3	2	4	2	3	3	1	4	1	3	3	4	4	4	3		

Figure 4 - Scored relationships between user requirements and the selected design parameters

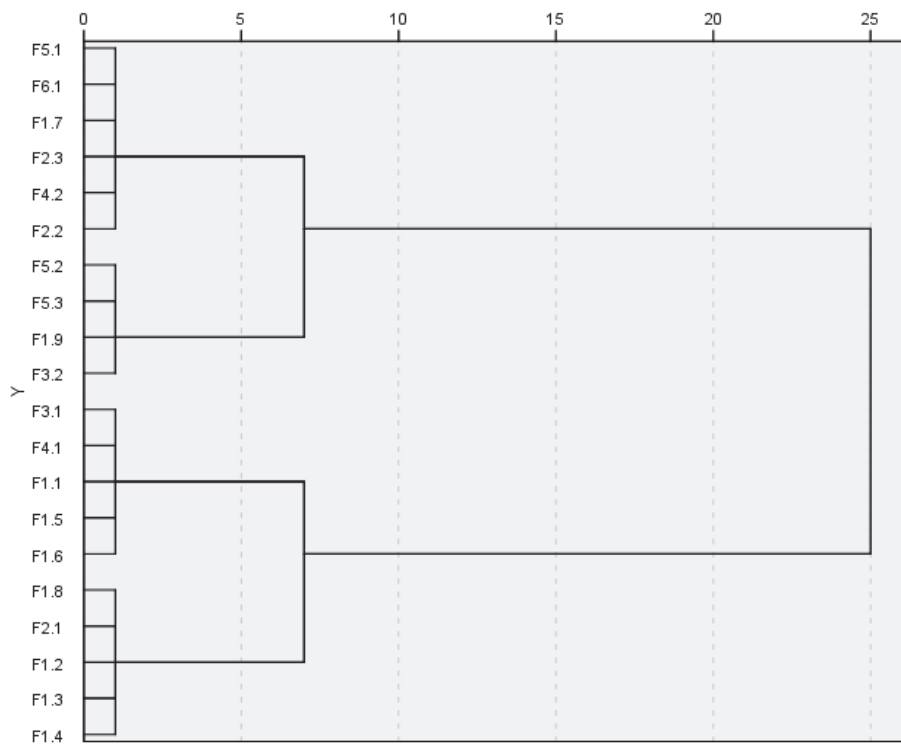
274

275

276

277 Ranking analysis and hierarchical clustering analysis were applied to the relative scores for  
 278 grouping the design parameters into  $k$  different groups in terms of the level of importance. Based on  
 279 the approach presented in (Mardia et al., 1979) the grouping  $k = \sqrt{n/2}$  was implemented, where  $n$   
 280 is the number of identified design parameters In this case the functional parameters ( $n=20$ ) yield a  
 281 number of groups of  $k=4$ , used as input values for the cluster analysis which produced the  
 282 dendrogram in Figure 5.

283



284  
285 **Figure 5 – Clustered dendrogram**  
286

287 The design parameters sorted in the 4 ranking classes evidenced the importance of some  
288 interoperability functions (F5.2 and F5.3) as well as of the dashboard practices in the result  
289 presentation (F3.2) and of the essential text presenting just the necessary information (F1.9).

290

291 **3.1.4 Design parameter correlations**

292

293

**Table 5 – Correlation between the design parameters**

	F1.1	F1.2	F1.3	F1.4	F1.5	F1.6	F1.7	F1.8	F1.9	F2.1	F2.2	F2.3	F3.1	F3.2	F4.1	F4.2	F5.1	F5.2	F5.3	F6.1
F1.1																				
F1.2	‡																			
F1.3	∇	◇																		
F1.4	+	+	◇																	
F1.5	◇	◇	◇	‡																
F1.6	◇	◇	+	∇	∇															
F1.7	+	◇	‡	◇	◇	‡														
F1.8	◇	‡	◇	‡	◇	◇	◇													
F1.9	+	◇	+	‡	⊥	+	+	◇												
F2.1	∇	+	+	+	⊥	‡	◇	+	‡											
F2.2	+	◇	+	‡	+	∇	‡	+	+	+										
F2.3	◇	◇	+	◇	◇	+	+	◇	+	+	◇									
F3.1	◇	◇	◇	◇	◇	+	◇	◇	◇	◇	+	+								
F3.2	+	◇	◇	◇	◇	◇	◇	◇	+	+	◇	+	◇							
F4.1	◇	+	◇	+	◇	◇	+	+	◇	◇	◇	◇	+	‡						
F4.2	◇	‡	◇	+	◇	◇	◇	+	+	◇	◇	◇	◇	+	+					
F5.1	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	+	◇				
F5.2	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	+	◇	+			
F5.3	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	+	◇	‡	+		
F6.1	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	+	◇	‡	+	‡	

294

295 The correlation between the functional parameters is presented in Table 5. Higher variability is  
296 encountered in the categories of usability (F1.1-F1.9) and presentation (F2.1-F2.3), while no  
297 correlations are more present in the interoperability category (F5.1-F5.3). The results of QFD  
298 analysis conditioned both software development and GUI interface. The design parameters of the  
299 first two cluster groups were realized (use of input values range, skimmable text, touch friendly  
300 interface, text readable on any size of monitor, dashboards practices in the results, multi-language  
301 menus, software interoperability, hardware interoperability, no installation need and use of open  
302 source encoding), while only a few of the third group (self-explanatory navigation labels and  
303 information button) and none of the last were considered. Also the negative correlation of certain  
304 parameters influenced the choices: for example the large site-wide buttons (F1.5) was not realized  
305 because it had strong negative correlation with skimmable text presenting only the necessary  
306 information (F1.9, which belongs to the first cluster group).

### 307 **3.2 Software development**

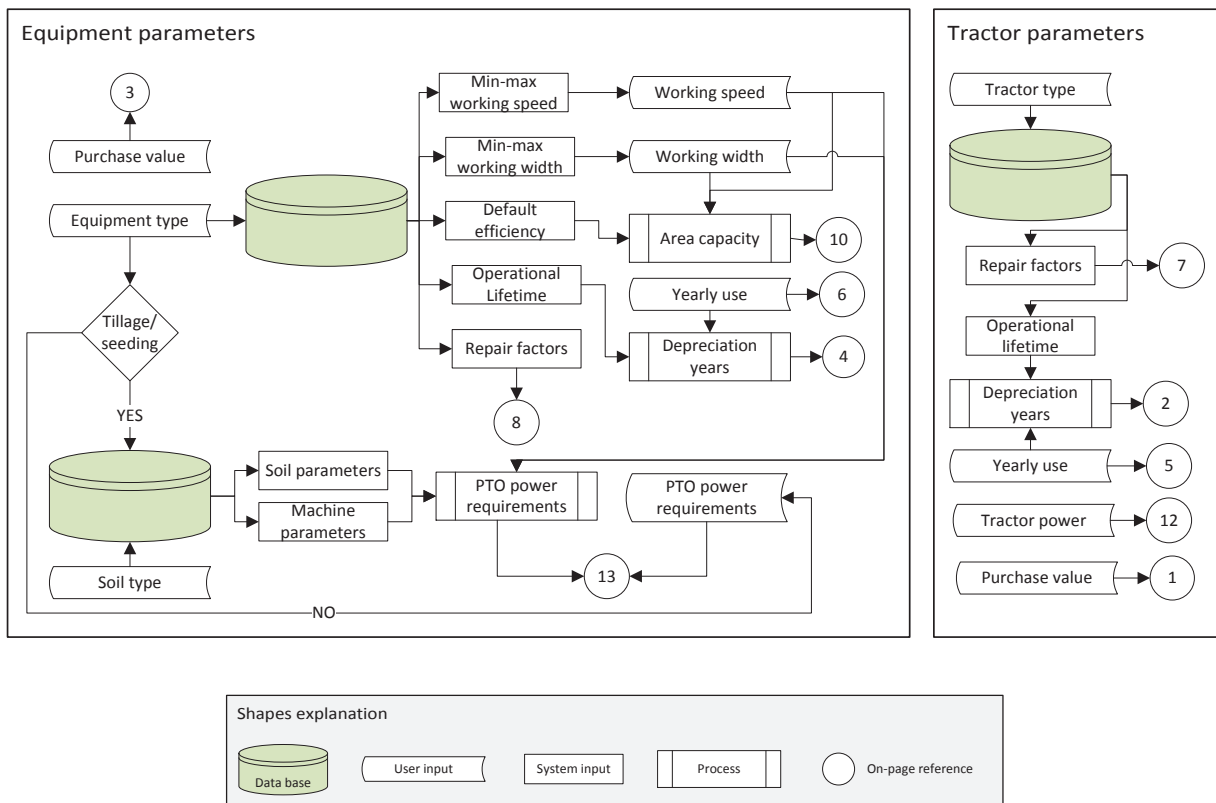
308 Mobile web and native apps are technology challenges to deliver cross-platform (F5.1 and F5.2 of  
309 QFD analysis) apps. Mobile web apps reside on server without installation on devices (F5.3 of QFD  
310 analysis) and it is possible make changes during the real-time execution, while native apps are in  
311 the internal storage of the single device after the install procedure and it is not possible to make  
312 changes in real time (Mao and Xin, 2014). The main weakness of native apps is that they must be  
313 developed separately for each platform and this leads to an increase of development time and costs.  
314 The development of native apps for different mobile operating systems requires the use of different  
315 programming languages. Moreover, once it is modified, users are obliged to update their apps to  
316 receive upgraded services.

317 The more practical approach of the mobile web app was chosen, using HTML language for the  
318 content part, JavaScript for the logic, and CSS as a presentation style (F6.1 of QFD analysis). Also,  
319 all the recent browsers support HTML5, JavaScript and CSS languages. Xin et al. (2015) indicates

320 that the cross-platform mobile development technology (JavaScript, HTML5 and CSS) used is a  
 321 viable solution for mobile apps. Mobile app characteristics are imitated by modern web apps  
 322 through rich user experiences. Even though the results may not be as attractive as native code, there  
 323 are some advantages, such as the web portability, and the readiness to create cross-platform apps.  
 324 A lot of work is required to build a mobile web app that appears and performs like a native app, and  
 325 also to fitting automatically various resolutions of devices (F2.3 of QFD analysis). To solve this  
 326 question AMACA application used a touch-optimized (F2.2 of QFD analysis) JavaScript library:  
 327 the jQuery Mobile (JQM). The JQM framework provides many features to support JavaScript basic  
 328 library. HTML5 local storage feature was used to store some variables which can be modified by  
 329 the user and are introduced as new parameters for calculations.

330 **3.3 Data processing**

331



332

333

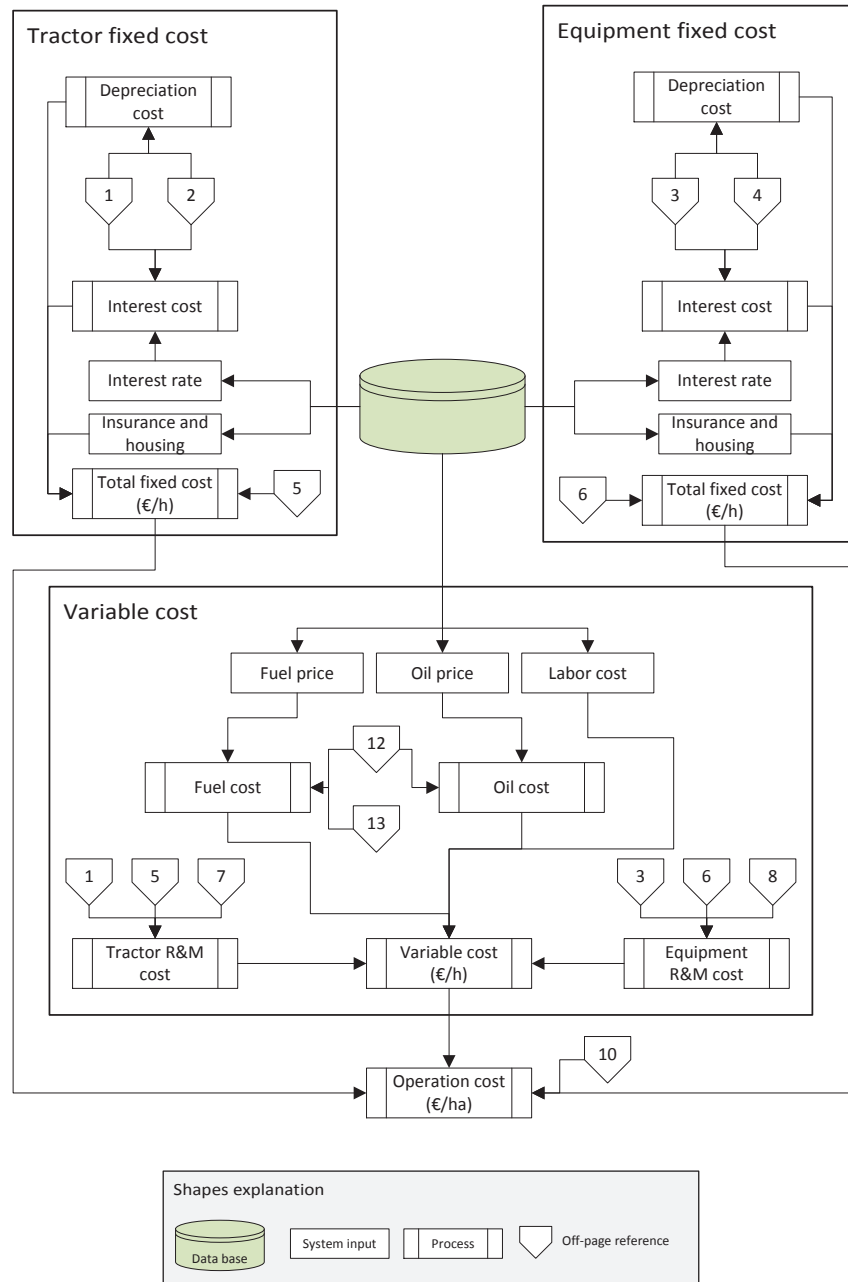
334

**Figure 6 – Flow diagram of data insertion of tractor and equipment parameters**



335 The data process follows the diagram of the Figure 6. Some parameters are entered by the operator,  
336 while others are selected from the targeted selection offered by the values in the database. For  
337 example the new value of the equipment or the tractor is entered by the user. The hours of work per  
338 year, the type of tractor are selected from values in the database. This allows the user to avoid large  
339 errors in data entry. Values suggested are by default for the most common parameters, as a function  
340 of the type of machine chosen (average speed, working hours per year, etc.).

341 The processing of implement's data allows for the calculation of the field unitary capacity, the  
342 power demand, the lifetime of the machine (Figure 6). Processing data of the tractor allows to  
343 calculate in a first phase to the duration (year) of the same. The parameter of the duration of the  
344 tractor and equipment allows the user to calculate the hourly fixed costs of the operating machine  
345 and the tractor, while the power demands and the working capacity allows to calculate the variable  
346 costs (fuel consumption, maintenance) and the operation costs per unit of area, as can be seen see  
347 from the scheme of Figure 7.



348

349

350

Figure 7 - Flow diagram of computation of fixed and variable costs

351

### 352 3.4 Application GUI

353 The app is composed by two main interface pages: Input and Results. Each page shares the same  
 354 navigation header for a quick switching between the pages and the footer. History tracking and back  
 355 button is also enabled on each page. A script for all the pages is implemented to automatically  
 356 adjust the display size according to the browser/device's resolution (F2.3 of QFD analysis). The

357 Input page is designed to make the user input as easy as possible (F1.9 of QFD analysis). This page  
 358 is divided into two sections: tractor data and machinery data.

359 The tractor data section allows the users to insert the required data of the examined tractor (Figure  
 360 8a). Input requirements are the yearly hours of use, the power (kW) and the purchase value of the  
 361 tractor (€). For the yearly hours of use and the tractor power a range slider is available (F1.7 of  
 362 QFD analysis).

363 Regarding the machinery data section, as illustrated in Figure 8b, after selecting the machine on a  
 364 drop down menu, the user must input the yearly hours of use, the required power (kW), the  
 365 machinery lifetime (h) and the purchase value (€). Then the operation working width (m), the  
 366 working speed (km h<sup>-1</sup>) and the consumables cost (€ ha<sup>-1</sup>) must be inserted. Also in this case, all the  
 367 above mentioned parameters may be chosen with the range slider (the range sliders vary in function  
 368 of the machine type).

369

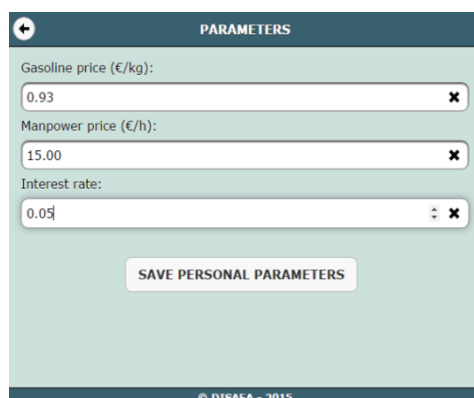
(a)

(b)

370

Figure 8 – Tractor input data (a) and machinery input data (b) interfaces

371 The “info” button (F1.8 of QFD analysis) in the page header of the Input page lets the user to access  
372 the instruction page where it is possible to find detailed information about the application use.  
373 HTML5 allows a local (on device) storage feature to store some variables. By tapping the “modify”  
374 button in the Instructions page it is therefore possible to change some parameters used for the  
375 calculations (Figure 9).

The image shows a mobile application interface titled "PARAMETERS". It features three input fields: "Gasoline price (€/kg)" with a value of 0.93, "Manpower price (€/h)" with a value of 15.00, and "Interest rate:" with a value of 0.05. Each input field has a small 'x' icon to its right. Below the input fields is a button labeled "SAVE PERSONAL PARAMETERS". At the bottom of the screen, there is a copyright notice: "© DISAFA - 2015".

376

377

**Figure 9 – General parameters interface**

378

379 The Results page (Figure 10) can be accessed by tapping the “calculate” button on the Input page. It  
380 provides the cost analysis of the tractor and of the machinery inserted in the input page. In detail,  
381 users can find a first table (F3.2 of QFD analysis) with the amount of the fixed costs for the tractor  
382 and of the implement (depreciation, interest and insurance) expressed in  $\text{€ y}^{-1}$ . For calculation  
383 purposes the total fixed costs and repair and maintenance costs are expressed as  $\text{€ h}^{-1}$ .

384 In the second table users can find costs for both the tractor and the equipment as fuel consumption  
385 and labor. The hourly cost of the operation (total fixed costs plus proportional costs) is reported at  
386 the end of the page (machines costs), as the cost of the operation per hectare (machinery operation  
387 cost) and the total operation cost ( $\text{€ ha}^{-1}$ ).

388

The screenshot shows the 'Results' page of the AMACA app. It features two tables. The first table compares 'Tractor' and 'Equipment' costs across various parameters. The second table lists individual 'PARAMETERS' and their corresponding 'Value'.

PARAMETERS	Tractor	Equipment
Name	Tractor 85 kW	Large round baler
Depreciation (€/year)	2274.61	3200.00
Interest (€/year)	2255.31	900.00
Insurance (€/year)	100.00	100.00
Total fixed costs (€/h)	9.26	21.00
Repair and maintenance (€/h)	3.91	17.84

PARAMETERS	Value
Manpower cost (€/h)	15.00
Fuel consumption (€/h)	11.29
Machines costs (€/h)	<b>78.31</b>
Field capacity (ha/h)	1.14
Machinery operation cost (€/ha)	<b>68.84</b>
Consumables (€/ha)	4.50
Total operation cost (€/ha)	<b>73.34</b>

© DISAFA - 2016

389

390

Figure 10- Results page

391

### 392 3.5 Results demonstration

#### 393 3.5.1 Case study

394 In order to demonstrate the results provided by the app and its applicability, a case study was  
 395 carried out. The case study was focused in the field operation of the forage harvesting. The input  
 396 parameters are listed in Table 6.

397

398

Table 6 - Input parameters and values of forage harvesting

Input	Value
Tractor yearly hours of use (h)	500
Tractor power (kW)	85
Tractor purchase value (€)	56 500

Type of machinery	Baler
Machinery yearly hours of use (h)	200
Machinery power requirement (kW)	30
Machinery lifetime (h)	1 500
Machinery purchase value (€)	25 000
Working width (m)	6
Working speed (km h <sup>-1</sup> )	5

399

400 In Table 7 are listed the outputs provided by the web mobile application AMACA for the case study  
401 mentioned before.

402

403

**Table 7 - Output values of the forage harvesting using AMACA**

<b>Output</b>	<b>Tractor</b>	<b>Equipment</b>
Depreciation (€ y <sup>-1</sup> )	1 576.88	2 666.67
Interest (€ y <sup>-1</sup> )	1 563.50	750.00
Insurance (€ y <sup>-1</sup> )	100.00	100.00
Total fixed costs (€ h <sup>-1</sup> )	6.48	17.58
Repair and maintenance (€ h <sup>-1</sup> )	2.71	14.87
Manpower cost		15.00
Fuel consumption (€ h <sup>-1</sup> )	-	11.29
Machines cost (€ h <sup>-1</sup> )	-	67.94
Field capacity (ha h <sup>-1</sup> )	-	1.95
Machinery operation cost (€ ha <sup>-1</sup> )	-	34.84
Consumables (€ ha <sup>-1</sup> )		8.00

Total operation cost (€ ha<sup>-1</sup>) - 42.84

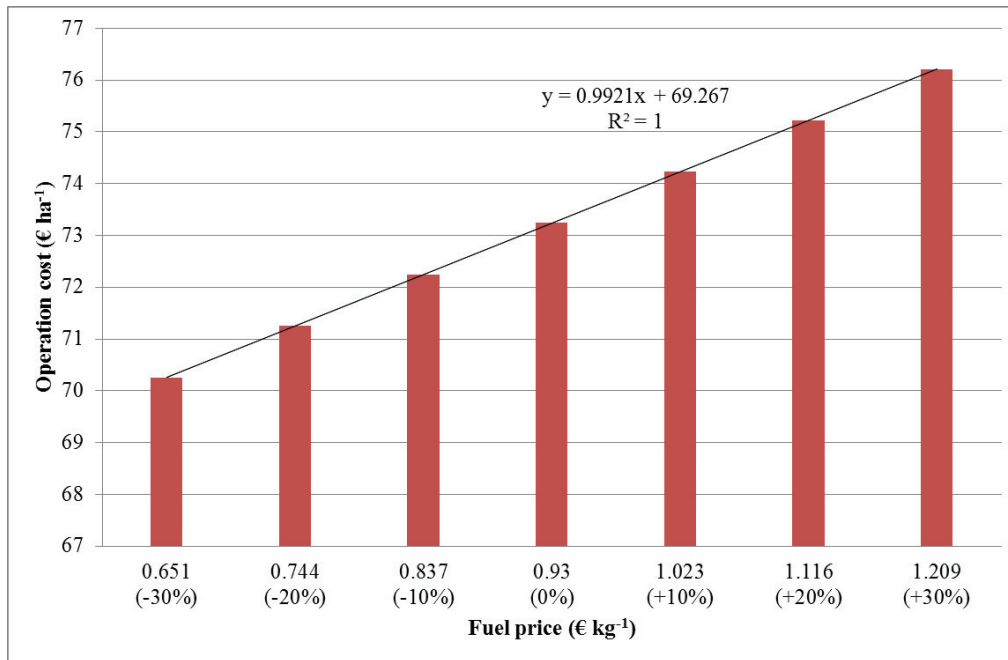
---

404

405 **3.5.2 Sensitivity analysis**

406 A sensitivity analysis was carried out to investigate the proper functioning of AMACA app. As it  
 407 can be seen in Figure 11, operation cost varies linearly according to fuel price variations. The slight  
 408 operation cost increase is reasonable since the fuel price directly affects only the fuel consumption  
 409 cost, which is a minor part of the whole operation cost.

410



411

412 **Figure 11 – Operation cost changes due to fuel price variations**

413

414 **3.5.3 Different tillage systems comparison**

415 One of the potential uses of AMACA is the cost comparison among different field operations. An  
 416 example is given concerning different tillage systems, whereas a traditional ploughing using a  
 417 moldboard plow, a chisel plow and a harrowing with a tandem disk harrow were considered.  
 418 Therefore the tractor power required to perform each operation was calculated. Being the tractor

419 power requirements lower than 85 kW, the same tractor type in the example of the case study  
 420 reported in chapter 3.5.1 was used.

421 Table 8 lists the rest of the input machine parameters used for the tillage comparison with the  
 422 AMACA program.

423

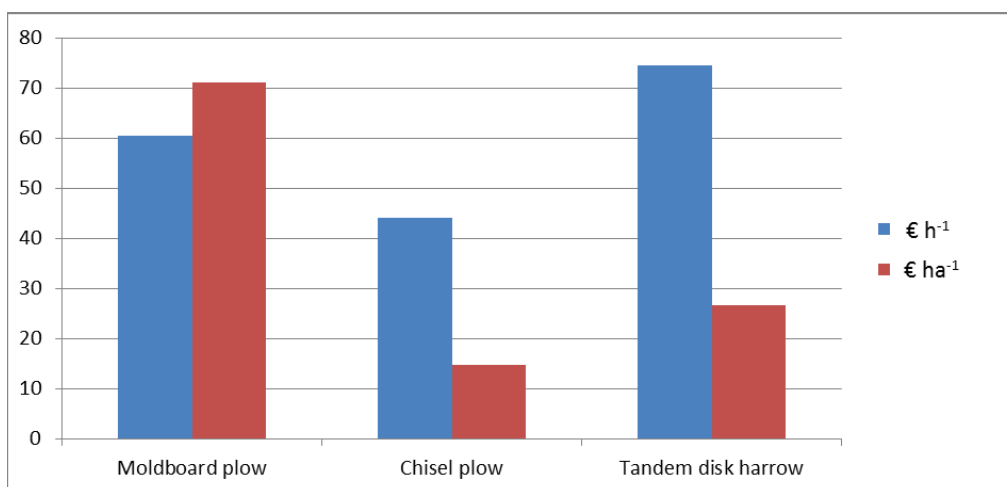
424

**Table 8 - Operating machines characteristics**

	Operating machine		
	Moldboard plow	Chisel plow	Tandem disk harrow
Use (h y <sup>-1</sup> )	80	80	80
Lifetime (h)	2,000	2,000	2,000
Purchase value (€)	14,000	5,000	30,000
Tractor power requirement (kW)	60	35	50
Working width (m)	2	5	5
Working speed (km h <sup>-1</sup> )	5	7	7

425

426 With these parameters AMACA produced the results shown in Figure 12.



427

428

**Figure 12 - Unit cost of different tillage types**

429



430 While the traditional ploughing with the moldboard plow produces higher costs for unit of surface,  
431 the highest hourly costs are given with the tandem disk harrow: an easy example like this may  
432 address the user to choice the most economic operation in function of his operative conditions.

#### 433 **4 CONCLUSIONS**

434 The process of the development of an easy-to-use web mobile app called “AMACA” (Agricultural  
435 Machine App Cost Analysis) for determining the machinery costs in different field operations was  
436 presented. The customer-driven QFD approach was implemented in order to link the user  
437 expectations with the design characteristics of the app.

438 The AMACA app is free<sup>1</sup>, readily available, and does not require any installation on the end users’  
439 devices. It is a cross-platform application meaning that it operates on any device through a web  
440 interface and major browsers support it. The results can be sent via e-mail to the operator, who can  
441 make subsequent calculations of the sensitivity by varying some parameters (fuel price, interest  
442 rate, field capacity, the power of the tractor coupled to the machine) and compare the results.  
443 AMACA app can support the decisions on whether to purchase a new equipment/tractor (strategic  
444 level), the use of own machinery or to hire a service, and also to select the economical appropriate  
445 cultivation system (tactical level). However, it is necessary to have reliable input information, and  
446 thus detailed data may be obtained using telemetry devices and monitoring systems installed on  
447 tractors (Mazzetto et al., 2009; Sørensen and Bochtis, 2010), but only the active participation of  
448 farmers may really improve the tool capabilities. This is an issue of further research and  
449 development of the app.

450

---

<sup>1</sup> <http://www.meccolt.unito.it/amaca/>

451       **REFERENCES**

- 452     Anderson, A.W., 1988. Factors affecting machinery costs in grain production, in: ASAE Paper No.88-1057.
- 453     ASABE, 2009. D497.6: Agricultural Machinery Management Data, in: ASABE Standards. St. Joseph,  
454       Mich.:ASABE.
- 455     ASABE, 2006. EP496.3: Agricultural Machinery Management, in: ASABE Standards. St. Joseph,  
456       MI.:ASABE.
- 457     ASAE, 2002. EP496.2. Agricultural machinery management, in: ASAE Standards. St. Joseph, Mich.:ASAE.
- 458     Bochtis, D.D., Sørensen, C.G.C., Busato, P., 2014. Advances in agricultural machinery management: A  
459       review. *Biosyst. Eng.* 126, 69–81. doi:10.1016/j.biosystemseng.2014.07.012
- 460     Brugger, F., 2011. *Mobile Applications in Agriculture, Magriculture*. Syngenta Foundation, Basel,  
461       Switzerland.
- 462     Buckmaster, D.R., 2003. Benchmarking tractor costs. *Appl. Eng. Agric.* 19, 151–154.
- 463     Busato, P., Berruto, R., 2014. A web-based tool for biomass production systems. *Biosyst. Eng.* 120, 102–  
464       116. doi:10.1016/j.biosystemseng.2013.09.002
- 465     Calcante, A., Fontanini, L., Mazzetto, F., 2013. Repair and maintenance costs of 4WD tractors in northern  
466       Italy. *Trans. ASABE* 56, 355–362.
- 467     Carnevalli, J.A., Miguel, P.C., 2008. Review, analysis and classification of the literature on QFD-Types of  
468       research, difficulties and benefits. *Int. J. Prod. Econ.* 114, 737–754. doi:10.1016/j.ijpe.2008.03.006
- 469     Chan, L.K., Wu, M.L., 2002. Quality function deployment: A literature review. *Eur. J. Oper. Res.*  
470       doi:10.1016/S0377-2217(02)00178-9
- 471     Fairbanks, G.E., Larson, G.H., Chung, D.S., 1971. Cost of using farm machinery. *Trans. ASABE* 14, 98–  
472       101.
- 473     Gartner, 2014. *Gartner Identifies the Top 10 Strategic Technology Trends for 2015*. Gartner.
- 474     Grisso, R.D., Kocher, M.F., Vaughan, D.H., 2004. Predicting tractor fuel consumption. *Appl. Eng. Agric.* 20,  
475       553–561.

- 476 Mao, X., Xin, J., 2014. Developing Cross-platform Mobile and Web Apps, in: World Conference on  
477 Computers in Agriculture and Natural Resources. University of Costa Rica, San Jose, Costa Rica, p. 8.
- 478 Mardia, K., Kent, J., Bibby, J., 1979. *Multivariate Analysis*. Academic Press.
- 479 Mazzetto, F., Calcante, A., Salomoni, F., 2009. Development and first tests of a farm monitoring system  
480 based on a client-server technology, in: *Precision Agriculture 2009 - Papers Presented at the 7th*  
481 *European Conference on Precision Agriculture, ECPA 2009*. pp. 389–396.
- 482 Piccarolo, P., Calvo, A., Del Treppo, S., 1989. Use of automatic computation in agricultural machinery data  
483 management, in: Dodd, V.A., Grace, P.M. (Eds.), *Proceedings of the Eleventh International Congress*  
484 *on Agricultural Engineering*. A.A.Balkema, Dublin, pp. 2661–2669.
- 485 Poozesh, M., Mohtasebi, S.S., Ahmadi, H., Asakereh, A., 2012. Determination of appropriate time for farm  
486 tractors replacement based on economic analysis. *Elixir Control Engg.* 47, 8684–8688.
- 487 Schiefer, G., 1999. ICT and quality management, in: *Computers and Electronics in Agriculture*. pp. 85–95.  
488 doi:10.1016/S0168-1699(99)00009-5
- 489 Schuler, R.T., Frank, G.G., 1991. *Estimating Agricultural Field Machinery Costs*.
- 490 Siemens, J.C., Bowers, W.W., 1999. *Machinery management: How to select machinery to fit the real needs*  
491 *of farm managers*, Farm Busin. ed. East Moline, Ill, John Deere Publishing.
- 492 Sørensen, C.G., Bochtis, D.D., 2010. Conceptual model of fleet management in agriculture. *Biosyst. Eng.*  
493 105, 41–50. doi:10.1016/j.biosystemseng.2009.09.009
- 494 Sørensen, C.G., Jørgensen, R.N., Maagaard, J., Bertelsen, K.K., Dalgaard, L., Nørremark, M., 2010.  
495 Conceptual and user-centric design guidelines for a plant nursing robot. *Biosyst. Eng.* 105, 119–129.  
496 doi:10.1016/j.biosystemseng.2009.10.002
- 497 Xin, J., Zazueta, F.S., Vergot, P., Mao, X., Kooram, N., Yang, Y., 2015. Delivering knowledge and solutions  
498 at your fingertips: Strategy for mobile app development in agriculture. *Agric. Eng. Int. CIGR J.* 2015,  
499 317–325.

Table 1 – Voiced user requirements for n agricultural management system

General category	ID	Specific requirement
Data aquisition	R1.1	Improved general knowledge of the production process
	R1.2	Effective documentation system
	R1.3	Detailed work time specification
	R1.4	Detailed cost elemets specification
	R1.5	Information search availability (quick access to information)
	R1.6	Easy and quick access to information
	R1.7	Data exchange interfaces
	R1.8	Available data bases
	R1.9	Reduction of user inputted errors
Decision making	R2.1	Resource optimization (e.g., labor, fuel)
	R2.2	Generation of tasks orders
	R2.3	Environmental benefits (e.g., soil compaction, resource usage)
	R2.4	Preventive maintenance
	R2.5	Benchmarking
Software / hardware / technology components	R3.1	Dedicated user-interface
	R3.2	Application roughness
	R3.3	Communication with internal databases
	R3.4	Communication with external databases
	R3.5	Availability in various devices

Table 1 - Selected design parameters grouped within six main categories.

Category	Description	ID	Design parameters
Usability	The usability of the application regards the level of convenience that the user navigates and getting familiar with the app with a minimum amount of potential errors. It also refers to the level that the app enables user to read and internalize information.	F1.1	Step-by-step functions
		F1.2	Tutorial
		F1.3	Low maximum number of steps (e.g. 3)
		F1.4	Self-explanatory navigation labels
		F1.5	Large site-wide buttons
		F1.6	Reduced pop-out menu
		F1.7	Use of input values ranges (thresholds)
		F1.8	Information button
		F1.9	Skimmable text presenting only the necessary information.
Presentation	Presentation refers to the visual appearance and organization of the user interface and of the provided information.	F2.1	Simple and minimalistic design
		F2.2	Touch friendly interface (e.g. line spacing)
		F2.3	Text should be readable on any size of monitor (Fit screen resolution)
Visualization	Visualization regards the input and output processes	F3.1	Pop-up menus for input selection

and has to do with the analytical features that are used for inserting the information and presenting the results

F3.2 Dashboards practices in the results presentation, such as tables and charts

Personalization Personalization regards the customization for different user profiles in order to cover the needs of experienced and especially inexperienced users

F4.1 Different user profiles (Farmers, Contractors, Administrator)

F4.2 Multi-language menus

Interoperability Interoperability with data sources and other applications

F5.1 Software interoperability (e.g. Adroid, IOS, Windows)

F5.2 Hardware interoperability: Wireless communication and Bluetooth

F5.3 No instalation need

Scalability Expandability for additional functions

F6.1 Use of open source encoding

**Table 1 – Measures of correlation degree for the design parameters**

<b>Symbol</b>	<b>Correlation degree</b>
‡	strong positive
+	weak positive
◇	no correlation
∨	weak negative
⌊	strong negative

Table 1 – Score on the selected requirements of different users groups

Requirement	Average score	Solely farmer	Farmer contractor	Farmer consultant	Solely contractor	Solely consultant	Machinery dealers
R1.1	3.12	3.11	3.00	4.50	2.13	5.00	1.00
R1.2	2.05	1.22	1.43	2.50	1.75	3.00	2.40
R1.3	4.52	4.19	4.50	4.50	4.88	4.67	4.40
R1.4	4.48	4.33	4.64	4.50	5.00	5.00	3.40
R1.5	3.05	2.11	2.79	3.50	3.25	3.67	3.00
R1.6	4.74	4.75	4.57	4.50	4.63	5.00	5.00
R1.7	1.83	1.11	1.43	1.50	1.63	2.33	3.00
R1.8	1.72	1.14	1.64	1.50	2.00	1.67	2.40
R1.9	4.45	4.42	4.21	4.50	4.50	4.67	4.40
R2.1	2.63	3.94	4.07	2.50	2.63	1.67	1.00
R2.2	1.98	3.17	3.14	2.00	1.38	1.00	1.20
R2.3	1.68	1.50	1.07	2.50	1.00	3.00	1.00
R2.4	3.75	4.53	4.71	4.00	4.88	3.00	1.40
R2.5	2.57	2.00	2.57	3.00	2.88	4.00	1.00
R3.1	3.81	3.50	4.00	3.50	3.88	4.00	4.00
R3.2	3.90	4.89	4.86	3.50	4.75	3.00	2.40



R3.3	3.25	2.31	2.79	3.50	3.25	3.67	4.00
R3.4	1.53	1.67	1.43	2.00	1.38	1.33	1.40
R3.5	4.29	4.22	4.36	4.00	3.88	4.67	4.60

---

Table 1 – Correlation between the design parameters

	F1.1	F1.2	F1.3	F1.4	F1.5	F1.6	F1.7	F1.8	F1.9	F2.1	F2.2	F2.3	F3.1	F3.2	F4.1	F4.2	F5.1	F5.2	F5.3	F6.1
F1.1																				
F1.2	±																			
F1.3	∇	◇																		
F1.4	+	+	◇																	
F1.5	◇	◇	◇	±																
F1.6	◇	◇	+	∇	∇															
F1.7	+	◇	±	◇	◇	±														
F1.8	◇	±	◇	±	◇	◇	◇													
F1.9	+	◇	+	±	⊖	+	+	◇												
F2.1	∇	+	+	+	⊖	±	◇	+	±											
F2.2	+	◇	+	±	+	∇	±	+	+	+										
F2.3	◇	◇	+	◇	◇	+	+	◇	+	+	◇									
F3.1	◇	◇	◇	◇	◇	+	◇	◇	◇	◇	+	+								
F3.2	+	◇	◇	◇	◇	◇	◇	◇	+	+	◇	+	◇							
F4.1	◇	+	◇	+	◇	◇	+	+	◇	◇	◇	◇	+	±						
F4.2	◇	±	◇	+	◇	◇	◇	+	+	◇	◇	◇	◇	+	+					
F5.1	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	+	◇				
F5.2	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	+	◇	+			
F5.3	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	+	◇	±	+		
F6.1	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	+	◇	±	+	±	

**Table 1 - Input parameters and values of forage harvesting**

<b>Input</b>	<b>Value</b>
Tractor yearly hours of use (h)	500
Tractor power (kW)	85
Tractor purchase value (€)	81 500
Type of machinery	Baler
Machinery yearly hours of use (h)	200
Machinery power requirement (kW)	30
Machinery lifetime (h)	1 500
Machinery purchase value (€)	30 000
Working width (m)	2.5
Working speed (km h <sup>-1</sup> )	7

**Table 1 - Output values of the forage harvesting using AMACA**

<b>Output</b>	<b>Tractor</b>	<b>Equipment</b>
Depreciation (€ y <sup>-1</sup> )	2 274.61	3 200.00
Interest (€ y <sup>-1</sup> )	2 255.31	900.00
Insurance (€ y <sup>-1</sup> )	100.00	100.00
Total fixed costs (€ h <sup>-1</sup> )	9.26	21.00
Repair and maintenance (€ h <sup>-1</sup> )	3.91	17.84
Traction cost (€ h <sup>-1</sup> )	13.17	13.17
Fuel consumption (€ h <sup>-1</sup> )	-	11.29
Variable cost (€ h <sup>-1</sup> )	-	42.31
Hourly costs (€ h <sup>-1</sup> )	-	83.31
Operation cost (€ ha <sup>-1</sup> )	-	73.24

**Table 1 - Operating machines characteristics**

	Operating machine		
	Moldboard plow	Chisel plow	Tandem disk harrow
Use ( $\text{h y}^{-1}$ )	80	80	80
Lifetime (h)	2,000	2,000	2,000
Purchase value (€)	14,000	5,000	30,000
Tractor power requirement (kW)	60	35	50
Working width (m)	2	5	5
Working speed ( $\text{km h}^{-1}$ )	5	7	7

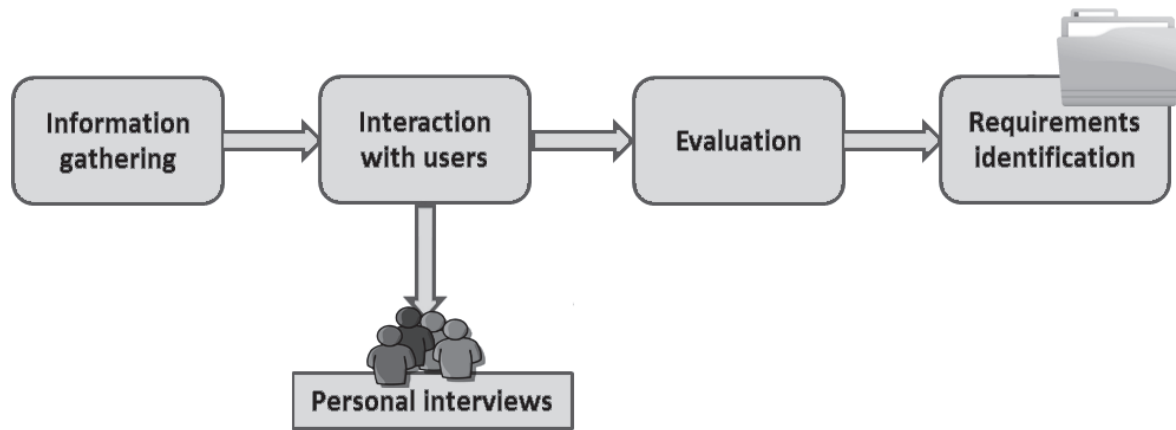
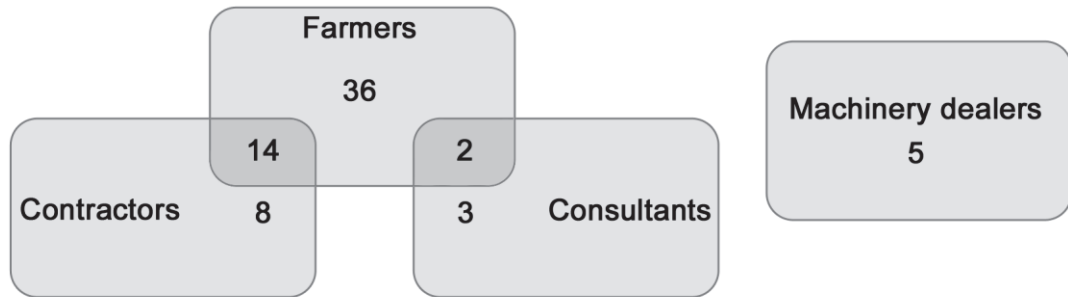


Figure 1- Identification of user needs

**Figure**

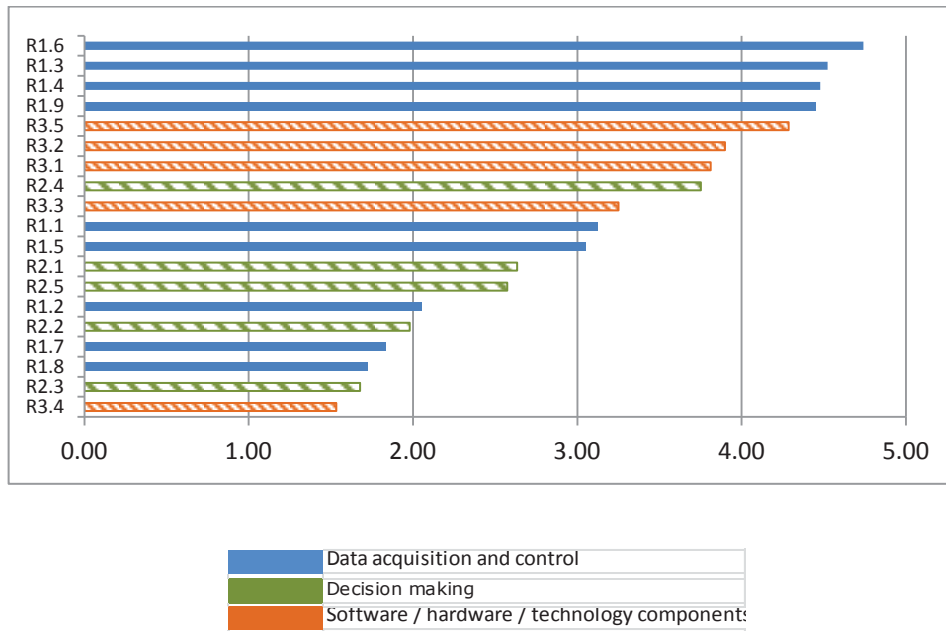
[Click here to download Figure: Figure 2.docx](#)



**Figure 1 - Distribution of different end user types**

# Figure

[Click here to download Figure: Figure 3.docx](#)



**Figure 1 - The average ranking of the users requirements.**



# Figure

[Click here to download Figure: Figure 4.docx](#)

		Importance rating	Usability									Presentation			Visualisation		Personalisation		Interoperability			Scalability						
			F1.1	F1.2	F1.3	F1.4	F1.5	F1.6	F1.7	F1.8	F1.9	F2.1	F2.2	F2.3	F3.1	F3.2	F4.1	F4.2	F5.1	F5.2	F5.3	F6.1						
User requirements	Data acquisition and control	R1.1	3.12		9							9	9				1		1									
		R1.2	2.05		1	9							9	9	1	1	1		1		3	1						
		R1.3	4.52									3						9										
		R1.4	4.48															9										
		R1.5	3.05		3		3	9	3	1	9	3	9				3	3		9	1							
		R1.6	4.74		9	9	9	9	9	3	9	3	9	9	9	9	3	1		9	9	3	3					
		R1.7	1.83									9																9
		R1.8	1.72									3																
		R1.9	4.45		3			1	9	9	9		1	3	9	3	1			3								
	R2.1	2.63									1						3			3								
	R2.2	1.98															1											
	R2.3	1.68															1											
	R2.4	3.75								3							3											
	R2.5	2.57									9		3				9	1		1								
	Software/hardware/technology components	R3.1	3.81		3	1	9	3	1	3	1		3	3	9	9	9	1	1	9	3	1	1		9		9	
		R3.2	3.90															1							9	9	1	
		R3.3	3.25																		3	9	9		9		3	
		R3.4	1.53																1		3	9	9		9		3	
		R3.5	4.29											3	9	9	1	1		1	9	9	9		9		9	
<b>Raw score</b>		65.31	93.04	86.14	81.58	55.64	28.71	117.91	98.28	128.13	76.74	117.61	117.61	61.98	158.08	6.39	118.01	118.02	120.97	120.97	103.04							
<b>Relative score (%)</b>		3.48%	4.96%	4.60%	4.35%	2.97%	1.53%	6.29%	5.24%	6.84%	4.09%	6.28%	6.28%	3.31%	8.43%	0.34%	6.30%	6.30%	6.45%	6.45%	5.50%							
<b>Ranking</b>		1	2	2	2	1	1	3	2	4	2	3	3	1	4	1	3	3	4	4	3							

**Figure 1 - Scored relationships between user requirements and the selected design parameters**

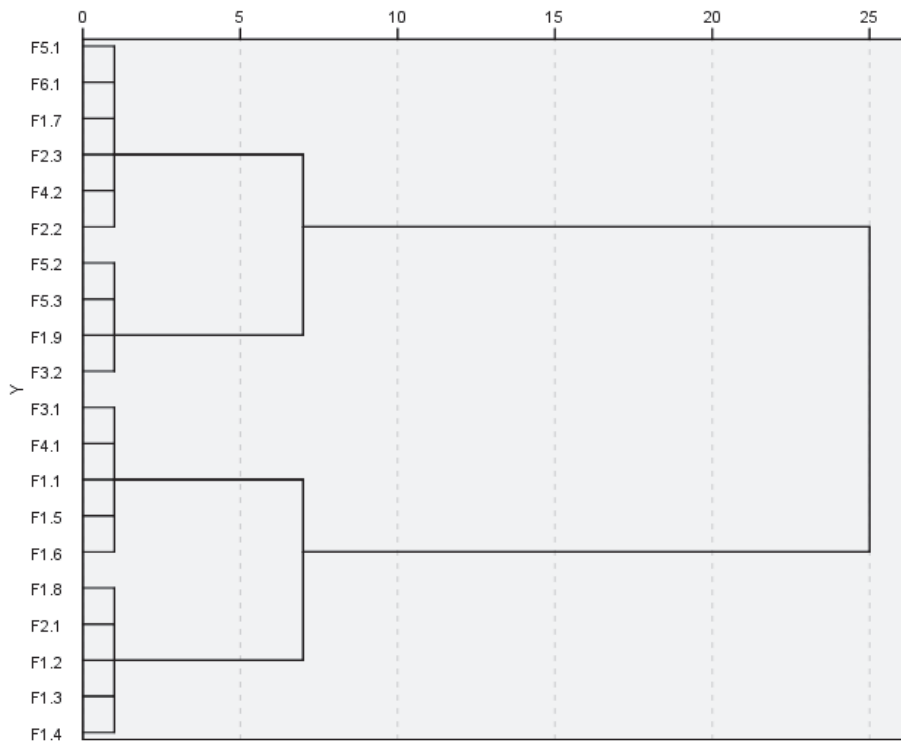


Figure 1 – Clustered dendrogram

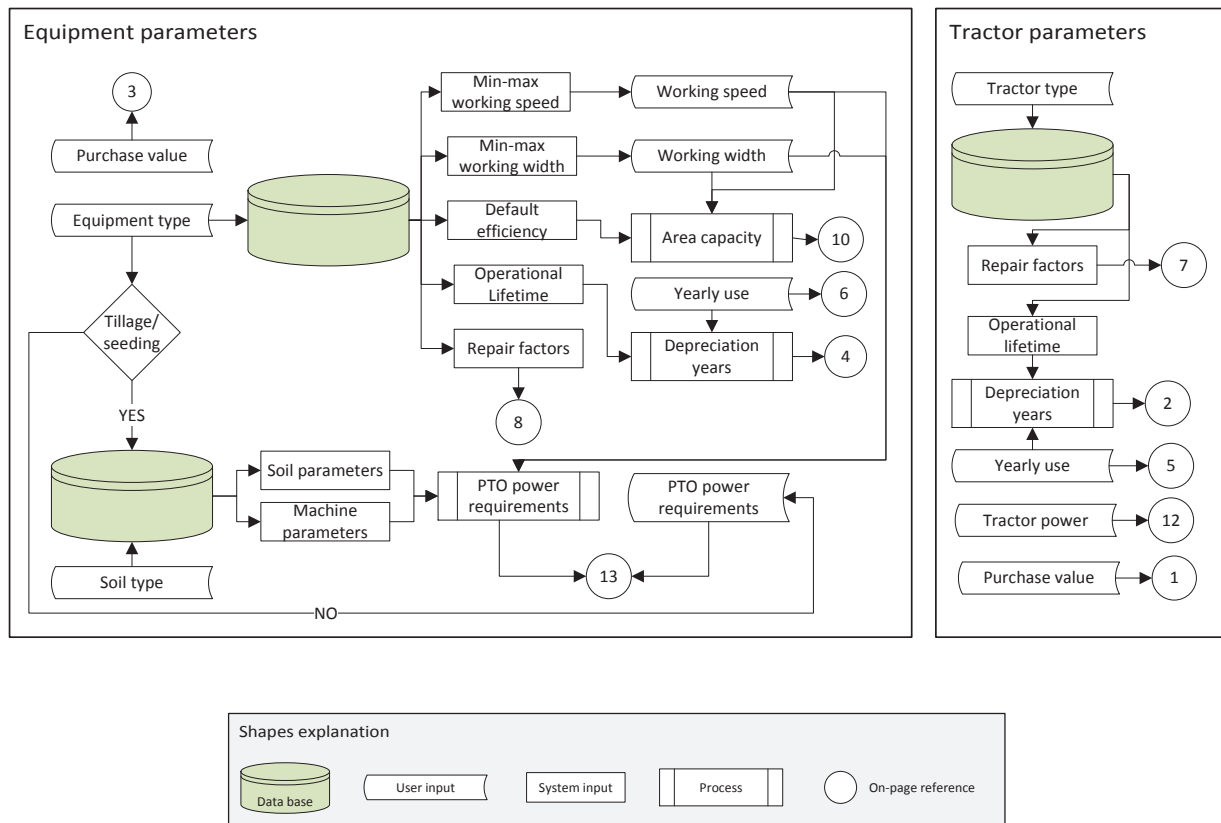


Figure 1 – Flow diagram of data insertion of tractor and equipment parameters

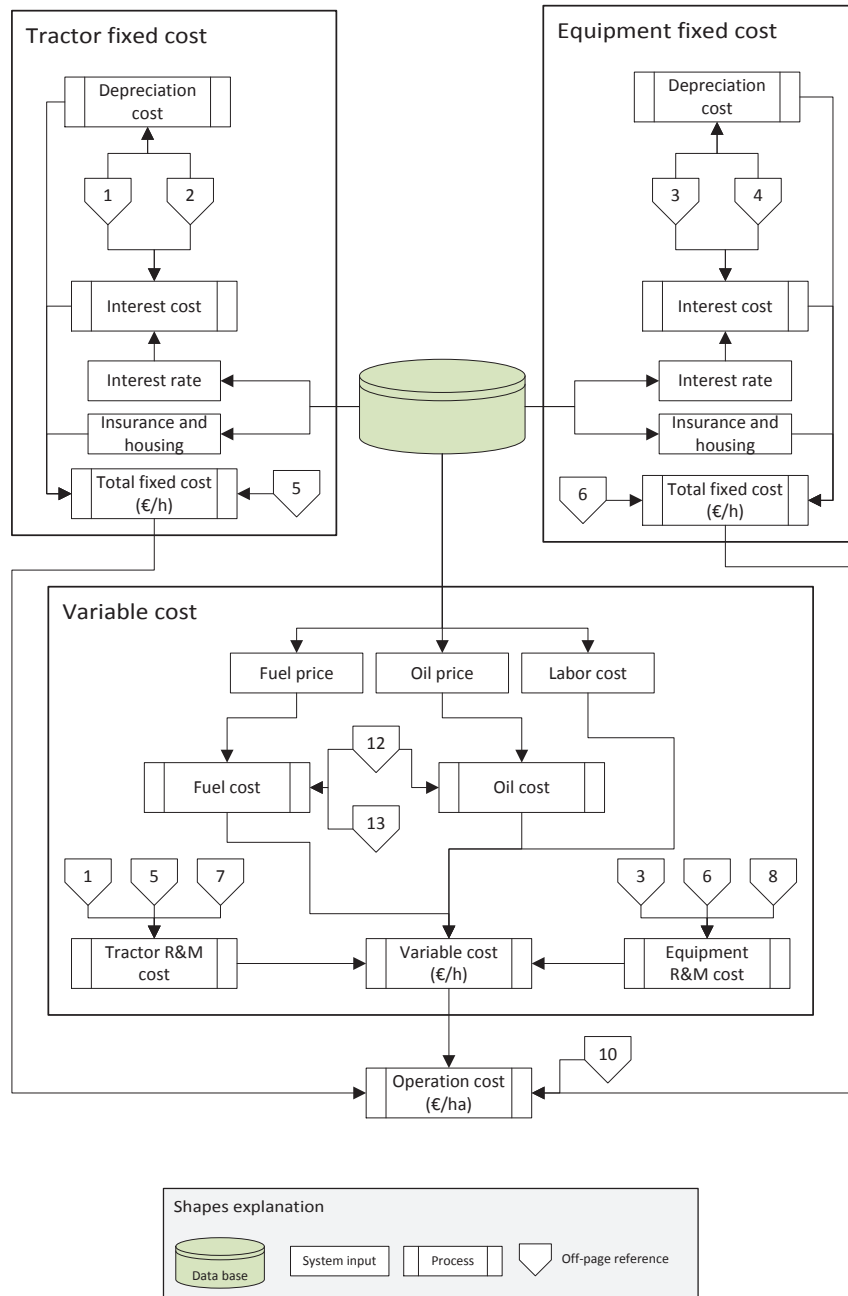


Figure 1 - Flow diagram of computation of fixed and variable costs

The screenshot shows the 'Input' tab of the AMACA app. At the top, there are 'Input' and 'Results' tabs. Below them is a header box with the text 'AMACA: AGRICULTURAL MACHINE APP COST ANALYSIS'. The main section is titled 'Insert your tractor data:'. It contains four input fields: 'Tractor name' with the text 'Tractor 85 kW', 'Yearly hours of use (h)' with a slider set to 500, 'Power (kW)' with a slider set to 85, and 'Purchase Value (€)' with a text input field containing '81500'.

(a)

The screenshot shows the 'Insert your machinery data:' section of the app. It features a dropdown menu for 'Type of machinery' set to 'Large round baler'. Below this are five sliders: 'Yearly hours of use (h)' set to 200, 'Power (kW)' set to 30, 'Machinery lifetime (h)' set to 1500, 'Working width (m)' set to 2.5, and 'Working speed (km/h)' set to 7. There is also a text input field for 'Purchase Value (€)' containing '30000' and another for 'Consumables (€/ha)' containing '4,5'. A 'CALCULATE' button is located at the bottom of the form. A footer at the very bottom reads '© DISAFA - 2015'.

(b)

Figure 1 – Tractor input data (a) and machinery input data (b) interfaces

## Figure

[Click here to download Figure: Figure 9.docx](#)



The image shows a mobile application interface titled "PARAMETERS". It features three input fields for numerical values, each with a clear (X) button on the right. The first field is labeled "Gasoline price (€/kg)" and contains the value "0.93". The second field is labeled "Manpower price (€/h)" and contains "15.00". The third field is labeled "Interest rate:" and contains "0.05". Below these fields is a button labeled "SAVE PERSONAL PARAMETERS". At the bottom of the screen, there is a copyright notice: "© DISAFA - 2015".

Parameter	Value
Gasoline price (€/kg)	0.93
Manpower price (€/h)	15.00
Interest rate	0.05

**Figure 1 – General parameters interface**

# Figure

[Click here to download Figure: Figure 10.docx](#)

AMACA		
Input		Results
PARAMETERS	Tractor	Equipment
Name	Tractor 85 kW	Large round baler
Depreciation (€/year)	2274.61	3200.00
Interest (€/year)	2255.31	900.00
Insurance (€/year)	100.00	100.00
Total fixed costs (€/h)	9.26	21.00
Repair and maintenance (€/h)	3.91	17.84
PARAMETERS	Value	
Manpower cost (€/h)	15.00	
Fuel consumption (€/h)	11.29	
Machines costs (€/h)	<b>78.31</b>	
Field capacity (ha/h)	1.14	
Machinery operation cost (€/ha)	<b>68.84</b>	
Consumables (€/ha)	4.50	
Total operation cost (€/ha)	<b>73.34</b>	

© DISAFA - 2016

Figure 1- Results page

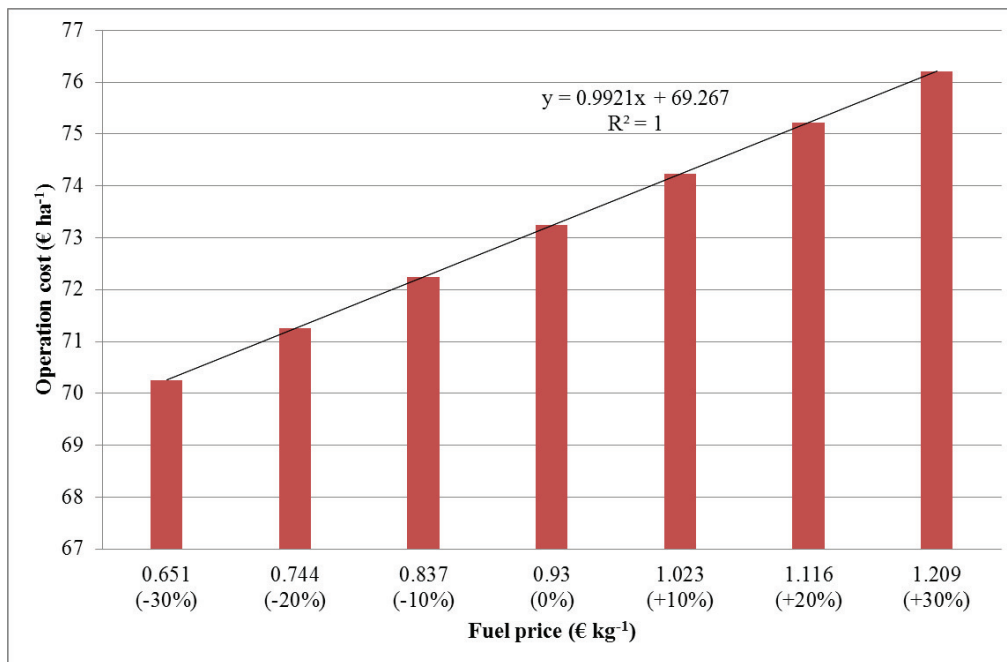


Figure 1 – Operation cost changes due to fuel price variations



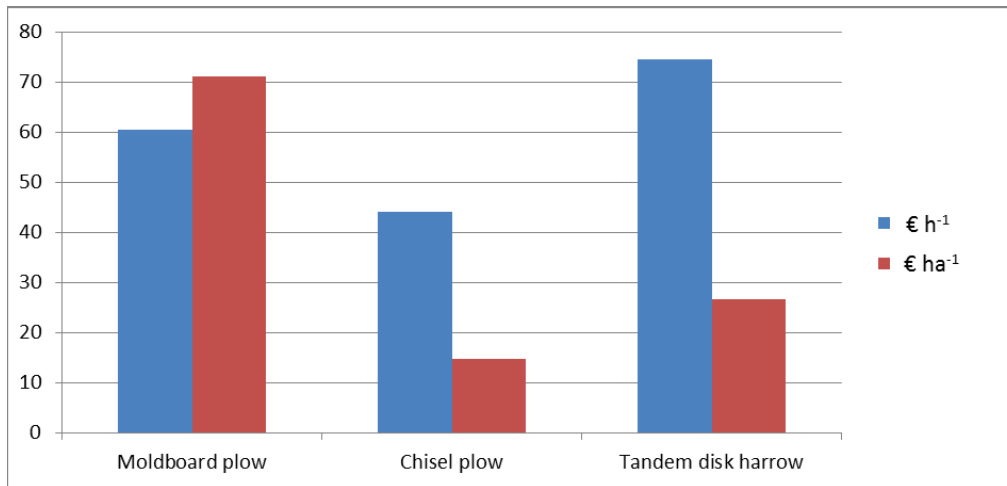


Figure 1 - Unit cost of different tillage types