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A WEB MOBILE APPLICATION FOR AGRICULTURAL MACHINERY COST ANALYSIS

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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

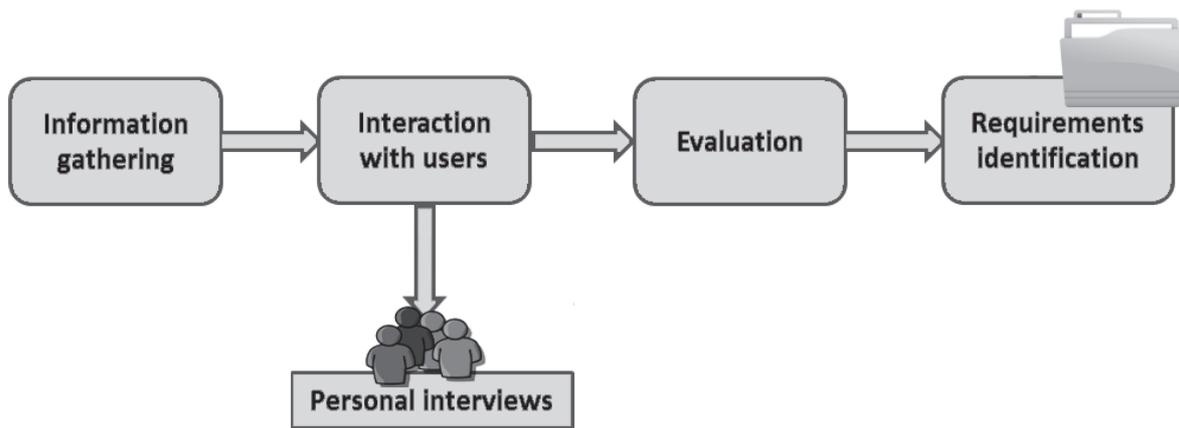


Figure 1 - Identification of user needs

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**

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

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

Scalability	Expandability for additional functions	F6.1	Use of open source encoding
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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 (€ 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

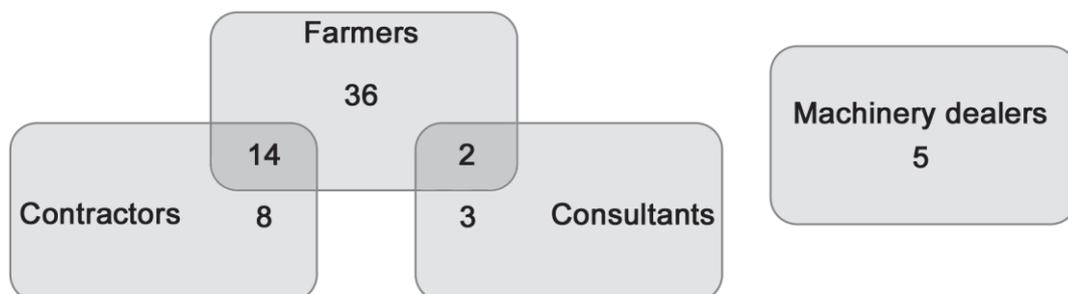
223 3 RESULTS AND DISCUSSION

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

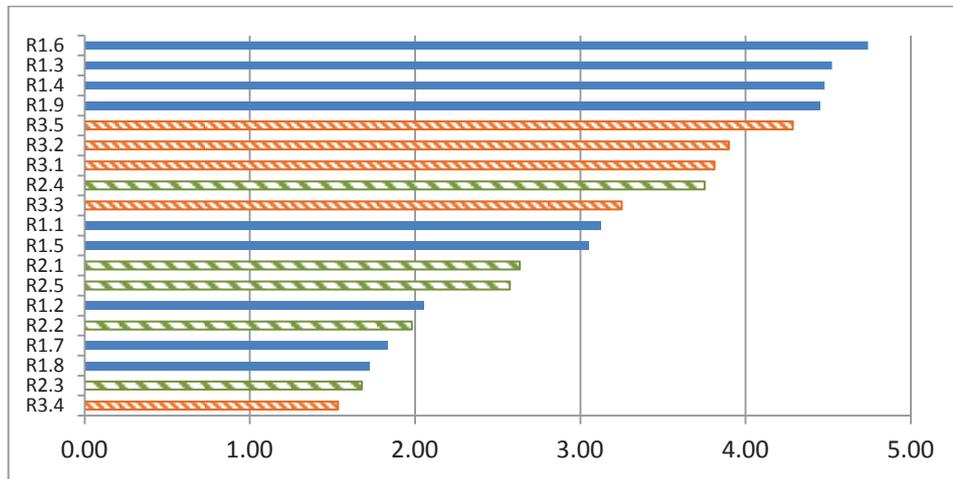
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Table 4 – Score on the selected requirements of different users groups

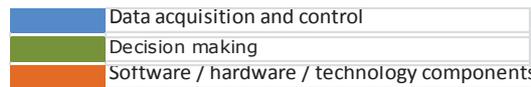
Requirement	Average score	Solely farmer	Farmer contractor	Farmer consultant	Solely contractor	Solely consultant	Machinery dealers
R1.1	3.12	3.11	3.00	4.50	2.13	5.00	1.00
R1.2	2.05	1.22	1.43	2.50	1.75	3.00	2.40
R1.3	4.52	4.19	4.50	4.50	4.88	4.67	4.40
R1.4	4.48	4.33	4.64	4.50	5.00	5.00	3.40
R1.5	3.05	2.11	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	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

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

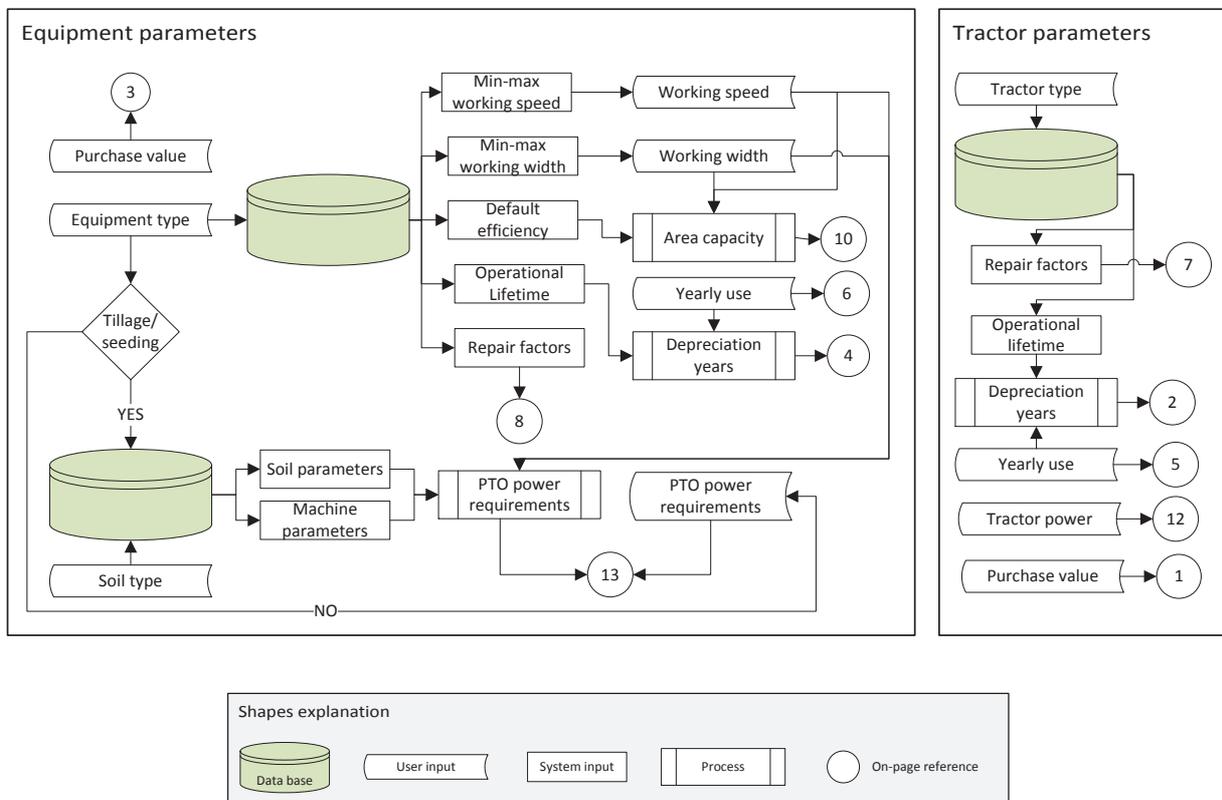
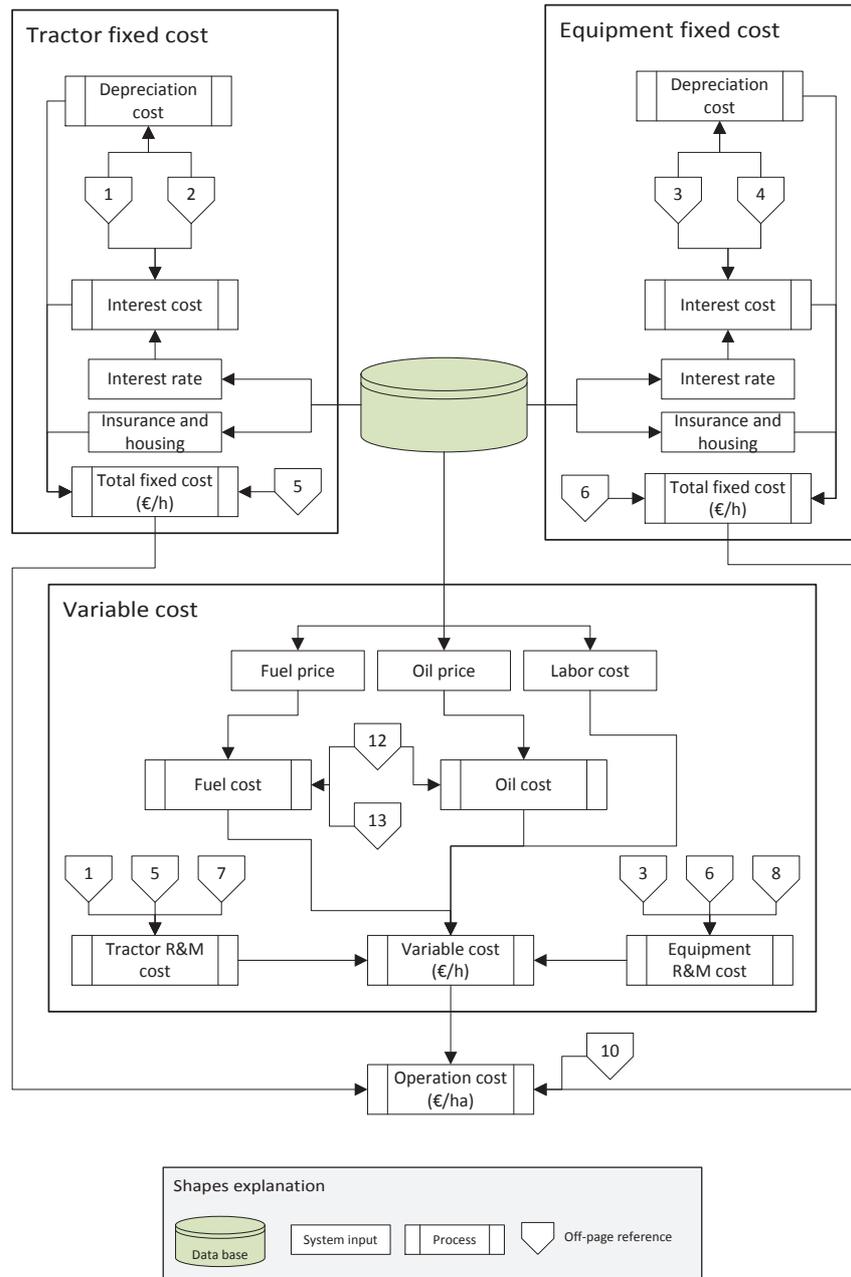


Figure 6 – Flow diagram of data insertion of tractor and equipment parameters

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

351

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

352 **3.4 Application GUI**

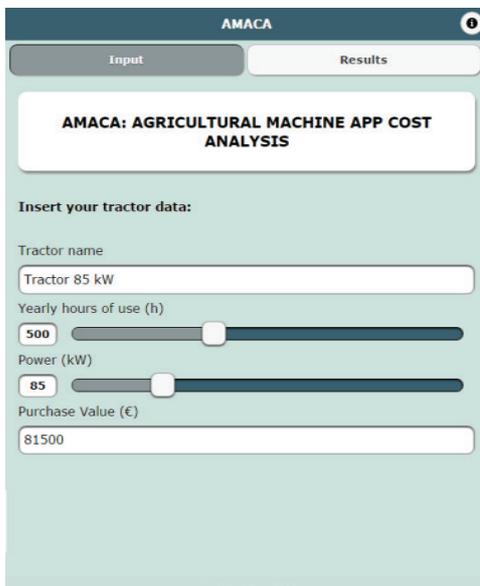
353 The app is composed by two main interface pages: Input and Results. Each page shares the same
 354 navigation header for a quick switching between the pages and the footer. History tracking and back
 355 button is also enabled on each page. A script for all the pages is implemented to automatically
 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.

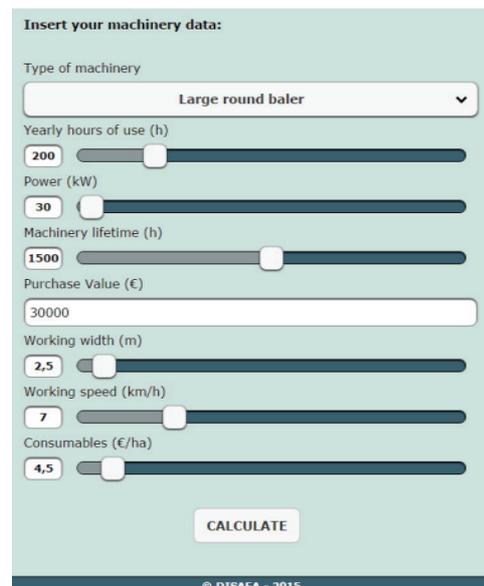
359 The tractor data section allows the users to insert the required data of the examined tractor (Figure
 360 8a). Input requirements are the yearly hours of use, the power (kW) and the purchase value of the
 361 tractor (€). For the yearly hours of use and the tractor power a range slider is available (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⁻¹) and the consumables cost (€ ha⁻¹) 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)

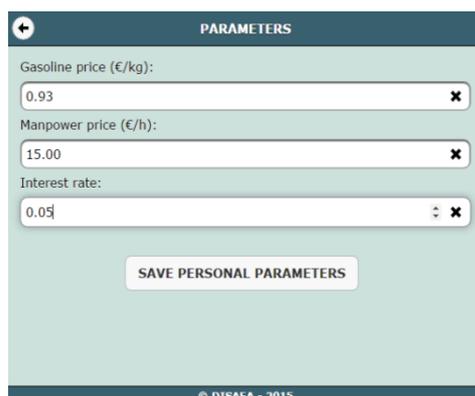


(b)

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 on the right side. 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 € y^{-1} . For calculation
383 purposes the total fixed costs and repair and maintenance costs are expressed as € 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 (€ ha^{-1}).

388

The screenshot shows the 'Results' page of the AMACA app. It features two tables. The first table compares costs for a Tractor and Equipment. The second table lists various parameters and their values.

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)	78.31
Field capacity (ha/h)	1.14
Machinery operation cost (€/ha)	68.84
Consumables (€/ha)	4.50
Total operation cost (€/ha)	73.34

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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 ⁻¹)	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

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

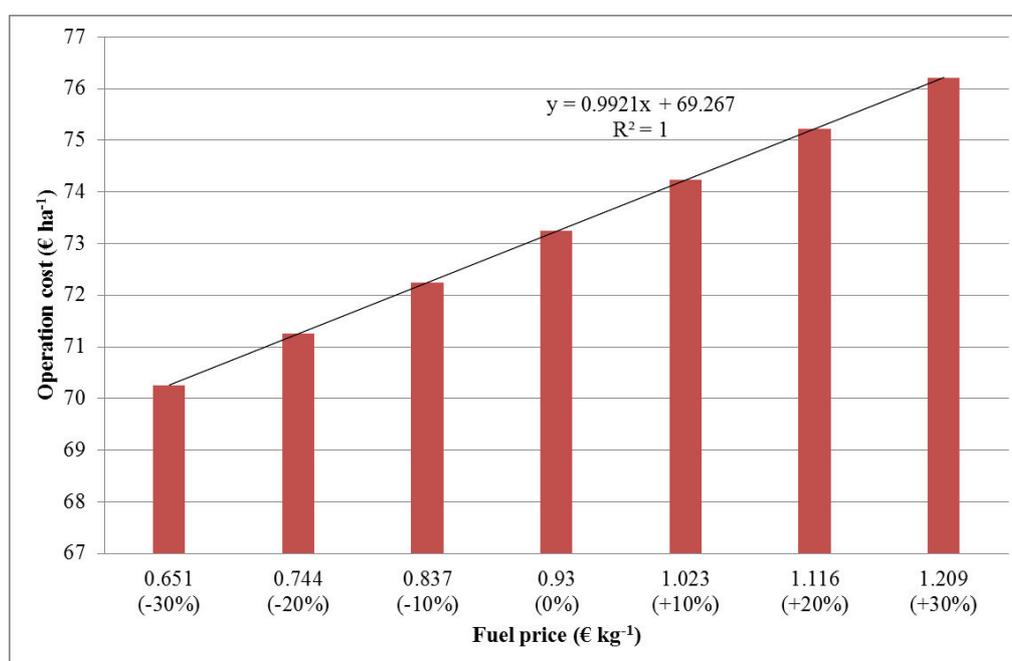
Total operation cost (€ ha ⁻¹)	-	42.84
--	---	-------

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

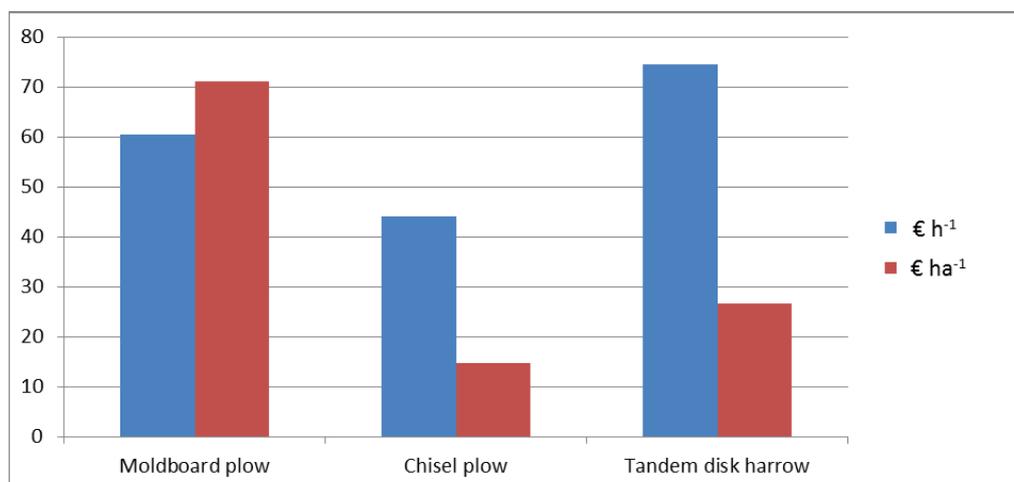
424

Table 8 - Operating machines characteristics

	Operating machine		
	Moldboard plow	Chisel plow	Tandem disk harrow
Use (h y ⁻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 (km h ⁻¹)	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 free¹, 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

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

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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

Symbol	Correlation degree
‡	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

Input	Value
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 ⁻¹)	7

Table 1 - Output values of the forage harvesting using AMACA

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

Table 1 - Operating machines characteristics

	Operating machine		
	Moldboard plow	Chisel plow	Tandem disk harrow
Use (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 (km h^{-1})	5	7	7

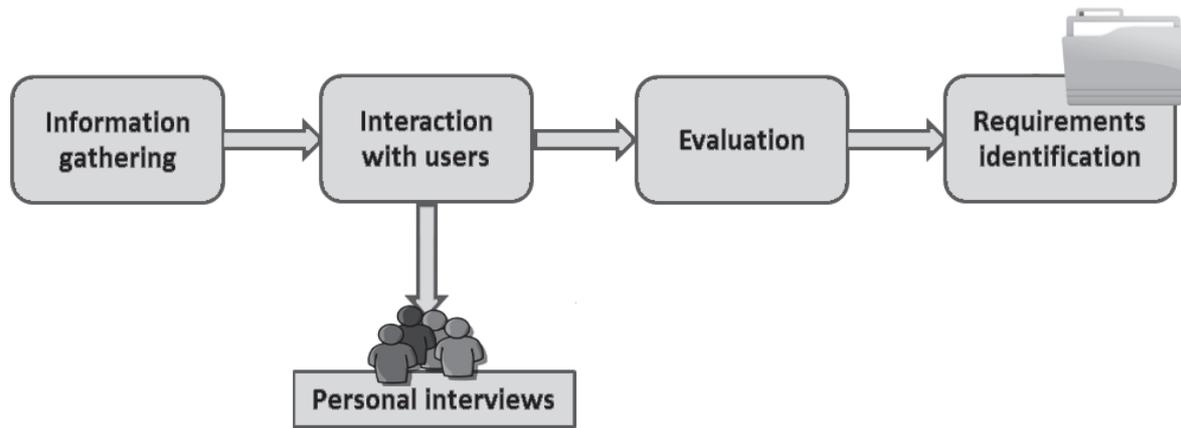


Figure 1- Identification of user needs

Figure

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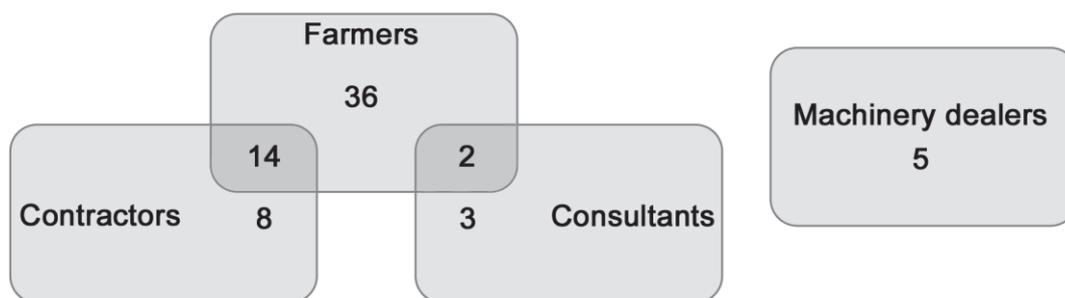


Figure 1 - Distribution of different end user types

Figure

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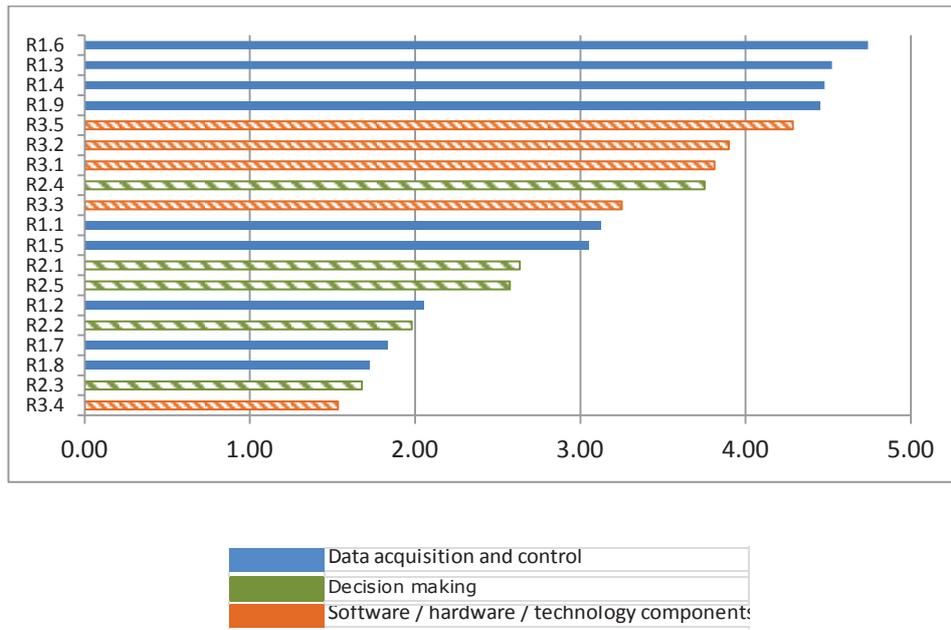


Figure 1 - The average ranking of the users requirements.

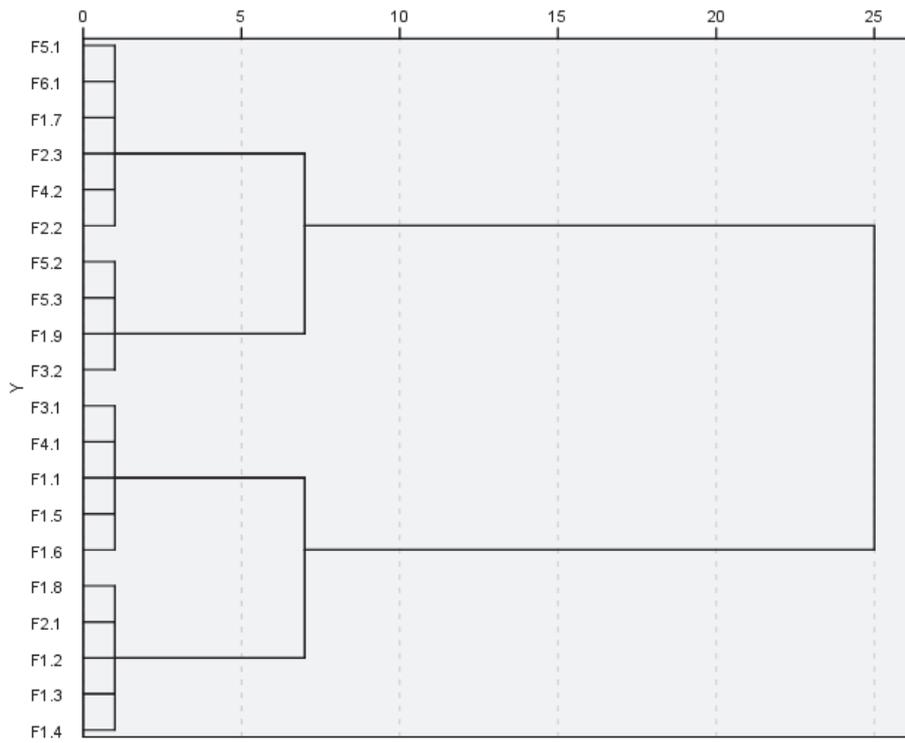


Figure 1 – Clustered dendrogram

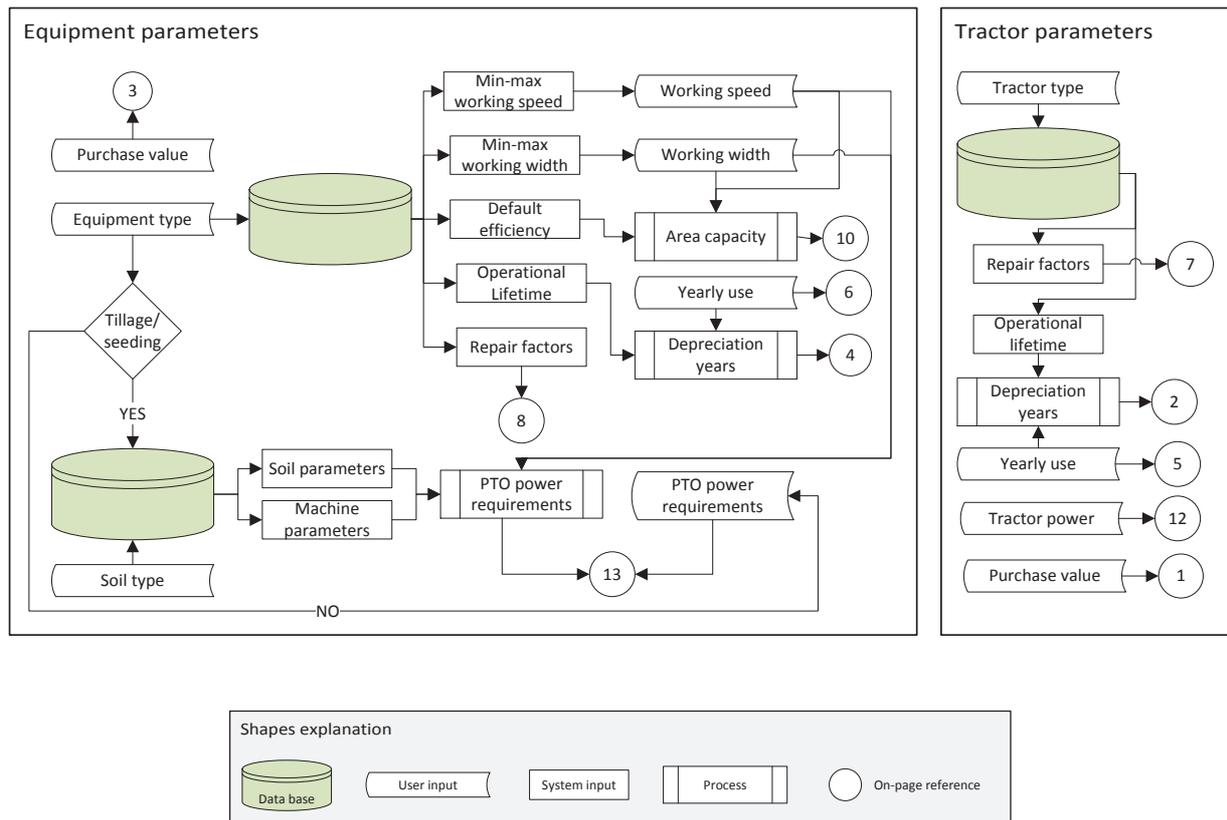


Figure 1 – Flow diagram of data insertion of tractor and equipment parameters

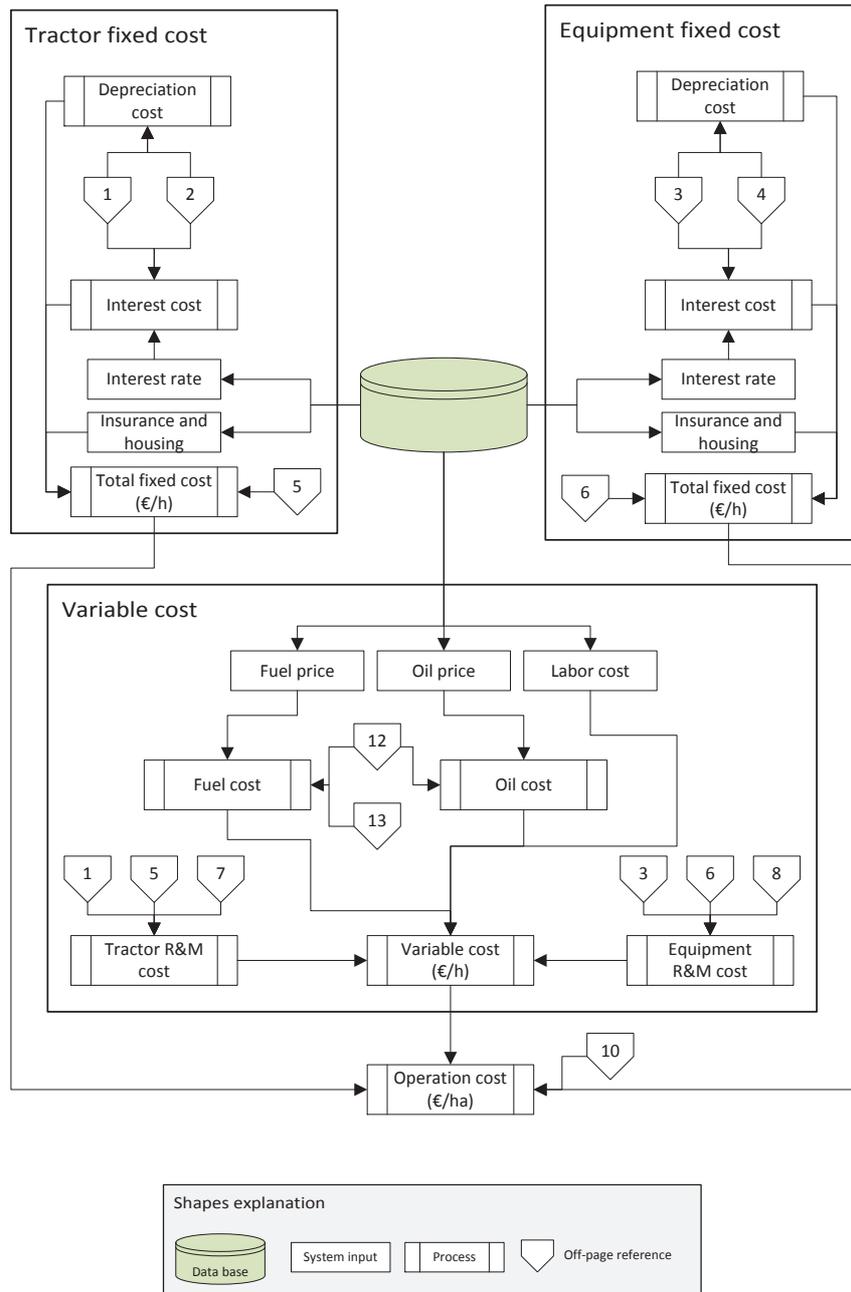


Figure 1 - Flow diagram of computation of fixed and variable costs

The screenshot shows the 'Input' tab of the AMACA app. The title is 'AMACA: AGRICULTURAL MACHINE APP COST ANALYSIS'. Under the heading 'Insert your tractor data:', there are four input fields: 'Tractor name' with the value '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 are six sliders: 'Yearly hours of use (h)' at 200, 'Power (kW)' at 30, 'Machinery lifetime (h)' at 1500, 'Purchase Value (€)' at 30000, 'Working width (m)' at 2.5, and 'Working speed (km/h)' at 7. A 'Consumables (€/ha)' slider is set to 4.5. A 'CALCULATE' button is at the bottom. A footer at the very bottom reads '© DISAFA - 2015'.

(b)

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

Figure

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The image shows a mobile application interface titled "PARAMETERS". It features three input fields for numerical values, each with a clear button (an 'x' icon) on the right side. The first field is labeled "Gasoline price (€/kg)" and contains the value "0.93". The second field is labeled "Manpower price (€/h)" and contains the value "15.00". The third field is labeled "Interest rate:" and contains the value "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)	78.31	
Field capacity (ha/h)	1.14	
Machinery operation cost (€/ha)	68.84	
Consumables (€/ha)	4.50	
Total operation cost (€/ha)	73.34	

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Figure 1- Results page

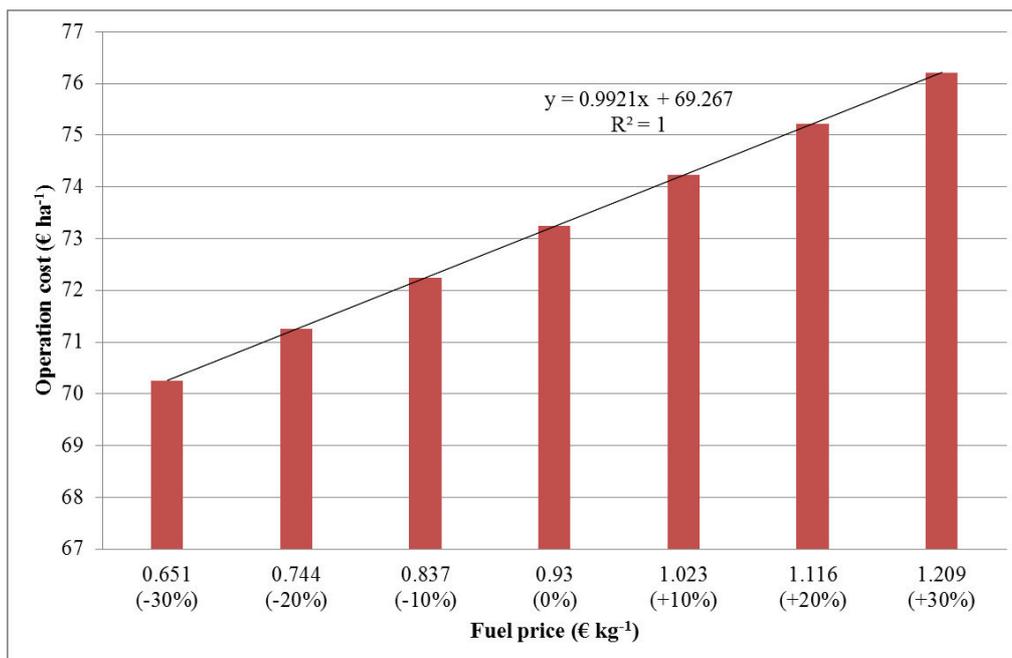


Figure 1 – Operation cost changes due to fuel price variations

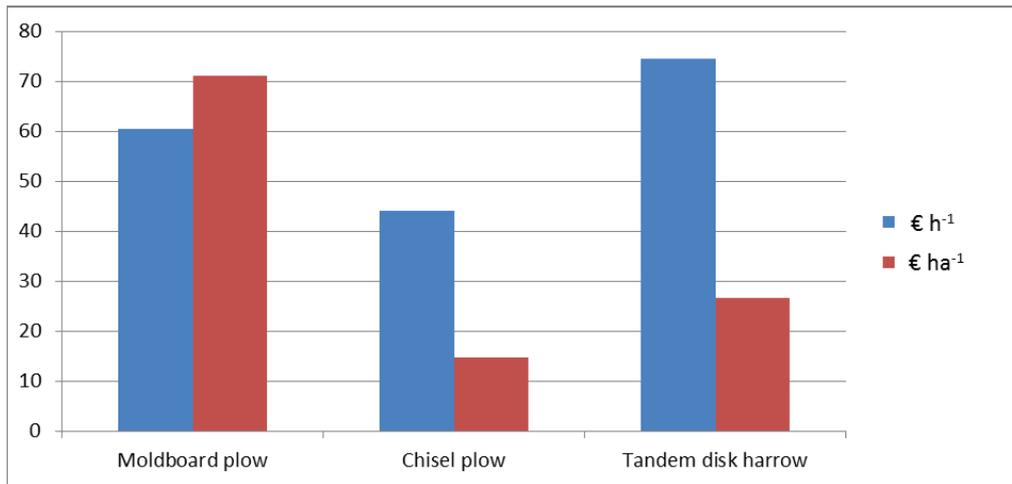


Figure 1 - Unit cost of different tillage types