ECONOMIC ANALYSIS OF UNMANNED GROUND VEHICLE USE IN CONVENTIONAL AGRICULTURAL OPERATIONS

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ABSTRACT

With the rapidly developing technology of robotic vehicles and smart farming systems, conventional agricultural practices are evolving towards a new era of automation that promises to increase their efficiency and effectiveness contributing towards the need for increased production with lower economic and environmental costs. However, such technology is relatively new and most of the resulting products and services are used in an experimental stage. The scientific community and the industry mainly focus on the advancement of technology with the introduction of new smart farming products and services for which an extensive economic feasibility analysis has not yet been carried out. To that end, the aim of the paper is to perform an economic feasibility assessment of replacing conventional agricultural machinery and human labor with "smart" farming systems. The methodology used adopts the principles of conventional agricultural machinery cost calculation adjusting them to the use of Unmanned Ground Vehicles (UGV). On this basis, the cost of performing a conventional agricultural operation with the use of a robotic vehicle is estimated for a variety of different production scenarios. The scenarios are distinguished on the basis of the cultivation size and the application of different operation management schemes, as for example different charging times and the use of multiple vehicles to avoid the dead times caused by charging. The results highlight the effect of operation management in the overall efficiency of such systems which eventually affects the operation duration and the resulting cost, despite the fact that there are still many factors that need to be further investigated for the accurate cost estimation, e.g. repair and maintenance cost, salvage value.

Keywords*:* UGV, economic analysis, precision farming, robotic system

1. INTRODUCTION

The employment of autonomous robotic systems is connected to the rapid evolution of technology (Bochtis et al., 2014) and the turning towards an online world were all operations are automated (Bochtis *et al.*, 2015; Ampatzidis et al., 2017). As a result, all the aspects of production and services are being robotized in order to satisfy increased demand more efficiently (Qureshi and Syed, 2014; Marinoudi *et al.*, 2019). The swift towards robotization is also evident in the agricultural sector since the need for increased efficiency of agricultural practices with a reduced environmental burden (Toledo *et al.*, 2014) drives the evolution of technology towards integrated "smart" farming systems that replace conventional agricultural machinery and practices (Bochtis *et al.*, 2011). Precision agriculture techniques that employ robotic agricultural systems have been introduced towards the reduction of inputs considering real field condition and needs (Bongiovanni and Lowenberg-Deboer, 2004). However, as it is the case with all the newly introduced technologies it is important to assess their feasibility to support their adoption and acceptance by their wider sector (Moradi et al., 2018). Also, in the context of a wider sustainability assessment it is important to determine the economic feasibility of agricultural robotic systems, and examine the costs and benefits arising from their use.

In the agricultural sector, Pedersen et al. (2006) performed an economic feasibility analysis to compare three conventional agricultural systems and the respective autonomous systems. Their work concluded that the robotic systems were more economically feasible than the respective conventional in all the cases tested. Toledo et al. (2014) assessed an electricity powered prototype mechanical weed control system to determine the energy costs of its operation concluding that the evolution of autonomous vehicle technology could further reduce the energy costs. Lampridi et al. (2019) attempted to propose a methodology for the economic analysis of the employment of robotic systems in arable farming adopting the methodology of conventional machinery use cost estimation (Lampridi et al., 2019). The methodology was implemented for the estimation of the cost of light soil cultivation.

The present paper attempts to examine the feasibility of robotic system's employment for a variety of different operational schemes concerning the robotic system's functionality. The robotic system considered for the purposes of this study is an autonomous UGV performing light soil cultivation (Grimstad and From, 2017). The application of the system is examined in the small and the large scale and it is compared to the relevant conventional application.

2. METHODOLOGY

In order to estimate the cost of robot employment in light soil cultivation the model presented in Figure 1 was followed. The model along with the respective equations is described in detail in Lampridi et al. (2019). In accordance with the calculation of the cost of performing a conventional agricultural operation, the total cost comprises of the Ownership and the Operational cost. The Ownership includes the capital and depreciation costs of the machinery as well as the housing and insurance costs. These costs can also be characterized as fixed costs since they are not related to the operation performed but they are determined by the machinery purchase cost and economic parameters such as the interest rate and the inflation.

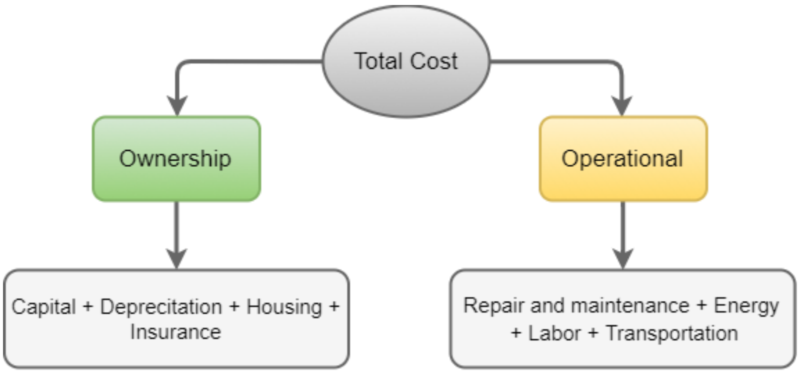

Figure 1. Cost Estimation Model

On the other hand, the operation cost is determined by the nature of the operation performed. It consists of the energy, the labor the transportation and the repair and maintenance cost. In the case of conventional machinery for the calculation of the repair and maintenance cost the ASABE standards are used (American Society of Agricultural and Biological Engineers, 2011). However, in the case of a robotic system such standards cannot apply. To that end, the approach of Bubeck et al. (2016) is followed. According to this approach the repair and maintenance cost of the robotic system is considered as a percentage of the respective conventional one.

3. Case Study

The aforementioned methodology was used to estimate the cost of performing light soil cultivation with the use of an unmanned ground vehicle in different operational schemes. The results are also compared with those of performing the operation with the use of a conventional system in order to maintain a base of reference. The system is examined in two different area scales. The Small Scale concerns an area of 10ha while the large scale an area of 100ha. In the case of the robotic system the same UGV is used in both small- and large-scale applications while in the case of conventional system different tractors are used. Table 1 presents the input parameters that were used for the cost estimation of the basic scenarios. In more detail a 40kw and an 80kw tractor caring a mechanical row-crop cultivator (C-shank) was selected for the small-scale and the large-scale scenarios respectively. In all the scenarios examined the interest rate is 9%, the inflation is 4% while the economic life of the machinery is 15 years.

Table 1. Input parameters for the economic model

		Robotic	Conventional Small-scale	Conventional Large-scale
Field operation parameters	**Working width (m)**	1.2	2.6	6.0
	Speed (km h^{-1})	4	8	8
Investment and ownership parameters	**Purchase price (€)**	50,000	40,000	130,000
	Implement purchase price (€)	1,000	3,000	6,000
	Salvage value (%)	10.9 [1,2]	10	10
	Housing coefficient	2.25	0.75	0.75
	Insurance coefficient	0.75	0.25	0.25
Machinery parameters	**Repair and Maintenance (R&M) factors**	-	0.003	0.003
		-	2	2
	Implement R&M factors	0.17	0.17	0.17
		2.2	2.2	2.2
	Machine power (KW)	3.4	40	80
	Energy cost (€ KWh^{-1})	0.145	0.496	0.496
	Labour Cost (€ h^{-1})	7.5[1]	15	15

[1] (Lampridi *et al.*, 2019) [2] (Propfe *et al.*, 2012)

For the robotic system basic scenario, the following assumptions were made. The UGV has a total power of 3.4kW and carries a 48V and 70Ah Lithium-Ion Battery. Considering that for prolonging the life-span of the battery it will discharge at a maximum 80% of its capacity before recharging and that the vehicle does not operate always on its maximum power, the UGV has an autonomous operation of maximum 1.34 hours. Additionally, the charging duration is calculated at 3.7 hours, considering a 15 A hourly charging rate. Regarding the assembly and disassembly of the machinery a total of 2 hours is considered. The UGV is equipped with a mechanical row-crop cultivator. It should also be stated that the UGV has the possibility to carry a second battery without any adjustments, doubling the operation time. A worker is considered for the observation of the equipment and the charging and battery replacement processes. The hourly wage is considered as the half of the respective conventional.

For the purposed of the present study the base line scenarios were compared to five alternative scenarios concerning the operational functionality of the robot and both in small- and large-scale applications. More specifically alternative scenarios that increase the efficiency of the robotic system were examined. These alternative scenarios include:

Scenario 1. Installation of a second battery of the same capacity in order to double the operation duration.

Scenario 2. Operation of the UGV's in pairs caring one battery. In this scenario for each UGV operating there is another one charging, waiting to replace the operating one. This scenario reduces the charging idle time from 3.7h to 1.02h.

Scenario 3. Operation of the UGV's in pairs caring two batteries. This scenario is the same as scenario 2 but doubles the operation time of the robot.

Scenario 4. Replacement of the battery in the operating UGV caring one battery. In this scenario the robot caries one battery which is replaced as soon as it discharges in order to avoid the idle charging time. However also in this scenario an idle time of 0.1h is considered for the replacement of the battery.

Scenario 5. Replacement of the battery in the operating UGV caring two batteries. The last scenario is the same as scenario 4 but with the use of two batteries in the UGV. In that case the idle time for replacing the batteries is increased in 0.2h.

4. Results

Figure 2 presents the results for the Small-Scale scenario. Considering the basic scenarios, the robotic system is 5.3 times more expensive than the conventional one. This is attributed to the low efficiency of the robotic system (approximately 25.6%) caused by the small operating time and long charging time. The total operation cost is 99.97 €·ha^{-1} for the robotic system compared to the 18.58 €·ha^{-1} of the conventional one. However, when installing a second battery (Scenario 1) the total cost is reduced to 64.37 €·ha^{-1} and the ratio to 3.46 times, while the efficiency increases to 39.3%. The system's efficiency is further increased (52.18%) when introducing robot operation in pairs with one battery per UGV (Scenario 2), however due to big investment costs the total cost of the system remains 3.50 times higher than the conventional one. The efficiency of the robotic system reaches up to 66% in Scenario 3 with the corresponding cost further reducing to 51.65 €·ha^{-1}. In the last scenarios (4 and 5) the efficiency reaches up to 82.67% and 83.3% respectively, which are very similar to the efficiency of conventional systems. The respective cots are approximately 1.7 times higher than the conventional (31.17 €·ha^{-1} for scenario 4 and 30.92 €·ha^{-1} for scenario 5).

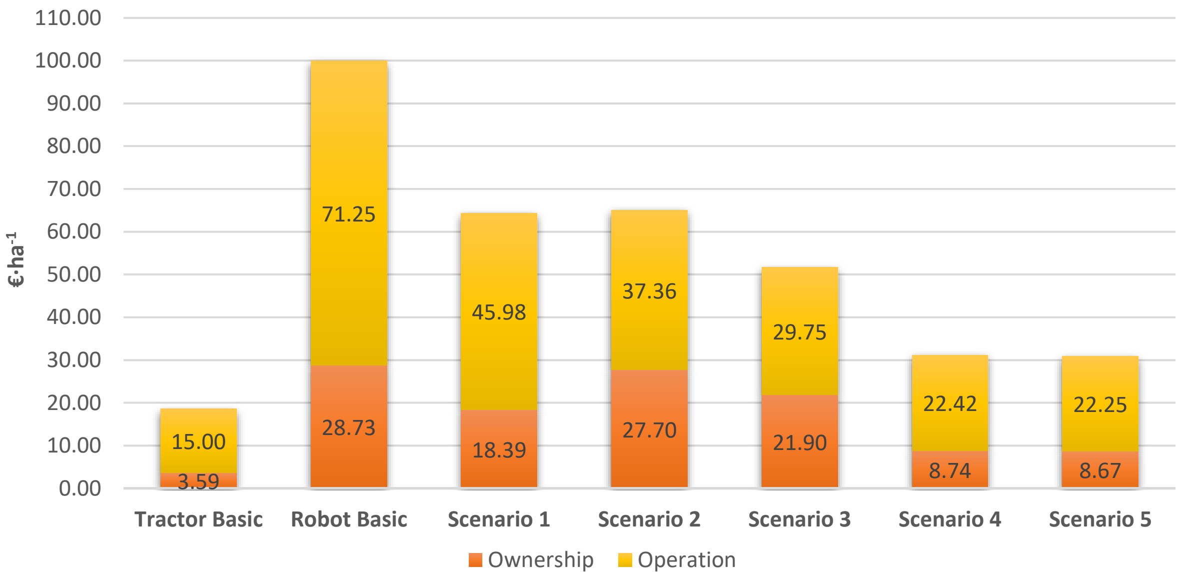

Figure 2. Total Cost – Small Scale Scenario (10ha)

Figure 3 demonstrated the results for the Large-scale scenario. In principle the robotic system is 3.48 times more expensive than the conventional one requiring 7 units to perform the operation in the given time frame, however, this ratio is reduced to 2.40 times when installing a second battery to the UGV (Scenario 1) (the vehicles required are reduced to five). In Scenario 2, eight vehicles are required to perform the operation (considering that four are operating and four are waiting to replace them) demonstrating that the high cost (42.74 €·ha^{-1}) of these robotic systems is a determining factor of their feasibility. Respectively in scenario 3 the cost is reduced to 34.64 €·ha^{-1} due to the increased efficiency of the system (50.8% in Scenario 2 and 67.1% in scenario 3). As was the case for the small-scale application, scenarios 4 and 5 demonstrate the highest efficiency (78.3% and 84.5% respectively) while their cost is only 1.49 and 1.38 times higher than the cost of the conventional system indicating its potential.

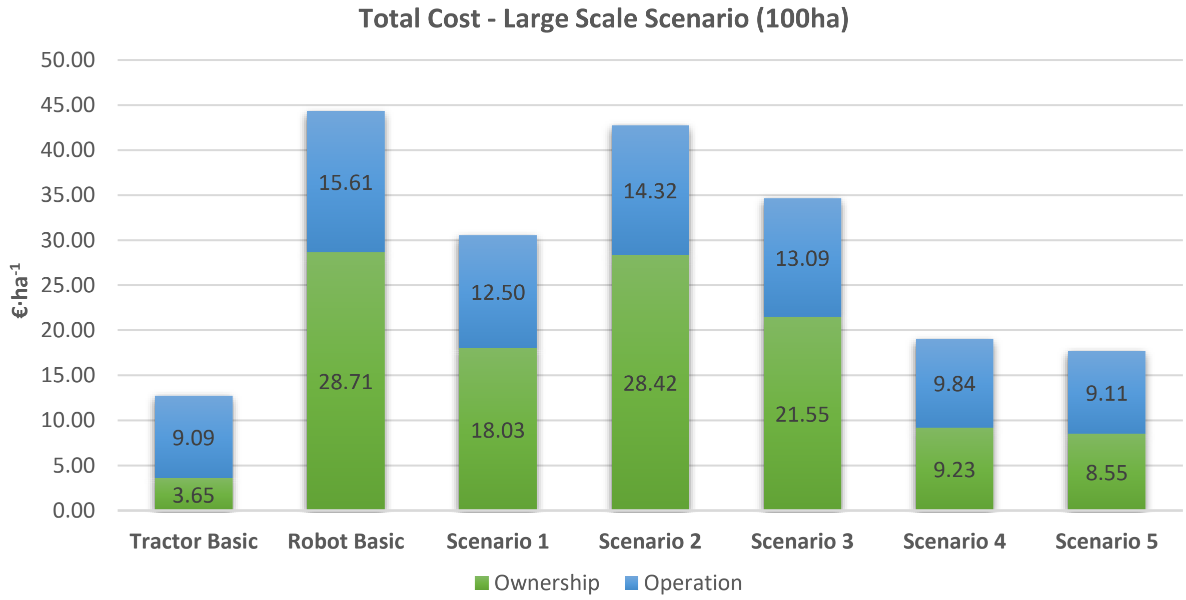

Figure 3. Total Cost – Large Scale Scenario (100ha)

5. Conclusions

The present paper attempted to step a little further towards the examination of the feasibility of adopting autonomous vehicles in conventional agricultural operations. According to the scenarios presented there is a promising potential however, the cost of these systems, which are still not massively produced, is high making them unprofitable compared to the conventional ones. Additionally, there are still areas for further investigation for the accurate cost estimation, as for example with the repair and maintenance cost or the salvage value. Nevertheless, several technical improvements can lead to the increase of their efficiency and their eventual release from the need of an operator thus further reducing operational costs.

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