v. 4, n. 8, 2024

Scientific Journal of Applied Social and Clinical Science

STUDY OF THE ECONOMIC VIABILITY OF AUTOMATING AGRICULTURAL MACHINERY FOR AN AUTONOMOUS PILOT SYSTEM IN THE PROVINCE OF QUEBEC, CANADA

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Abstract: The main costs that affect the economic viability of automation projects in conventional tractors are component costs and engineering development costs that increase the implementation cost. This work studied the economic viability of automating conventional tractors, being defined in two scenarios: without automation and with automation. For the study, a utility tractor used on small agricultural properties in the Canadian province of Quebec was used as a basis. Thus, a feasibility analysis of automating conventional tractors was carried out using economic indicators with the results obtained after determining revenues in both scenarios with corn production. The indicators in the scenario without automation proved to be a viable project with an interesting internal rate of return at 67.82% and payback close to 2 and a half years after the investment and NPV of CAD 72,543.69, and it was observed that when using tractors with automation pointed out as a viable project, due to the evaluation the internal rate of return at 82.88%, well above the MARR at 19.97%, payback just over 2 years and NPV of CAD 204,532.58 in the region analyzed, showing an efficiency of 182 % above the conventional tractor in the period. A sensitivity analysis was also carried out, in which the behavior of the net present value was validated depending on the variation in the efficiency scenario of both tractors, thus also altering the minimum attractiveness rates with the quantity of bags produced and evaluating the costs are reduced over time. The project demonstrated a need to add value to the price of the final product so that the investment is recovered in less time.

Keywords: tractor; computing systems; financial management.

INTRODUCTION

The future in technological terms is already present in our daily lives, whether in any area of our society; and, when it comes to agriculture, it is no different. Despite this large presence of technology, it is necessary to consider the level of acceptance and applicability to each reality of professionals in the agricultural sector. With wide options available to producers and companies in the sector, when it comes to devices used in the field, it was observed that agriculture is not averse to technology. Being applied in the most diverse ways, from trivial humidity sensors to fully autonomous equipment (Thomasson et al., 2019).

As expressed by Molin et al. (2015), precision agriculture has greatly helped in the efficiency and use of land by taking into consideration, spatial and temporal changes in crops, in the same way the autonomous system applied to agricultural machines comes to help operators work in a more agile way, effective and bringing security to them. However, the greatest progress for the agricultural sector occurred through the dispersion, costing and improvement of the precision of positioning devices, mainly the large distribution of microprocessors, equipment that enabled the use of data with greater precision, greater agility in processing and the appearance of embedded systems in rural tractors (Raupp, 2012).

With the great use of technology in the agricultural sector, we enter the fourth industrial revolution, or also called Agriculture 4.0, which applies high-performance computational parameters, sensing systems, communication and connections between devices. Such autonomous technology, by incorporating precision agriculture, agricultural automation and robotics, big data mechanisms and the Internet of Things, or also called "Internet of Things" [IoT], helps with important issues such as reducing working time, mitigate operational errors, mitigate accidents, assertiveness in operations with support systems for taking measures, reducing employee exposure to accidents, reducing losses to the operator and companies (producers, farms, etc.), making a system responsive and safe (Lisbinski et al, 2020).

The agricultural sector has been battling the same issue since the Industrial Revolution, with people leaving the countryside and migrating to urban centers. But at the same time, the world population is expanding and creating a need for more food. However, with less labor on farms there is also a demand to carry out more activities with fewer resources, whose procedures that were previously painful, with a great need for labor and energy costs, are being transformed with the help of the application of automation. for simple and uncomplicated processes, and thus improving crop productivity and profitability (Lamas, 2019; Lisbinski et al, 2020; Milton, 2021).

Organizations across the planet have offered different ways of using autonomous equipment and systems, such as John Deere, which uses an autopilot system, on-board computers, data generation and remote controls, devices that become work and driving tools, called AutoTrac, in which the tractor moves through the field with the farmer still in the cab acting as pilot (Deere & Company, 2023; Grilli, 2022).

As Milton (2021) says, the company Case IH has frequently worked in favor of autonomy, demonstrating the five distinct levels in its expansion plans. Level one of automation is the line follower, level two is about improving the coordination of tractor cabin systems, level three is highly mechanized machines, level four is autonomous inspected and level five is a fully autonomous vehicle without any person in the cabin.

Even though the purpose of automation in the field is to provide facilities in your daily routine, some issues obstruct such progress on properties: implementation costs. So farm owners need to recognize the cost effectiveness of using technologies and hiring increasingly specialist professionals (Azevedo, 2022).

Every project and organization, whatever it may be, aims to increase its financial returns, so, to help with decision-making regarding the investments to be made, economic viability analysis tools are used to direct the real condition that the investment will describe. with a certain time (Fagundes et al., 2020). According to Floreano and Cortezia (2019), the analysis of economic viability is an indispensable element for assessing risks and designing the next steps for investments in any company or project.

The present study aims to study the economic viability of automating conventional tractors in corn production, through the decomposition of economic indicators in scenarios of agricultural machinery work systems in soil preparation, planting and harvesting.

MATERIAL AND METHODS

LOCATION AND CHARACTERIZATION OF THE PROVINCE'S CULTURES

Agriculture takes part in the entire province of Quebec, with an estimated operating area of 6.3 million hectares, which makes up 5% of the total area. The regions with the highest percentage of agricultural area depending on the extent of their territory are: Central Quebec (93%), Montérégie (86%), Estrie (69%) and Chaudière-Appalaches (67%) (Government of Quebec, 2020).

The field is mainly oriented towards animal production, with dairy production being the main one, accounting for 57% of the companies, while corn is the main vegetable production. In Quebec, the agricultural production sector covers approximately 28,000 farms. As for the organic sector, there are approximately 3,000 companies with organic certification, of which 90% are involved in agriculture. Maple production, in specific, there are 1,030 bushes (Government of Quebec, 2020).

Activity in the province of Quebec generated market revenues of US$9.1 billion, including at least US$500 million for 6 of the 17 administrative regions. The regions share 61% of the revenue, being: Montérégie (30%), Chaudière-Appalaches (18%) and Center Quebec (14%) (Government of Quebec, 2020).

The studies were carried out in the province of Quebec, which allows the cultivation of a diversity of crops: blueberries, cranberries, strawberries and raspberries, fruits and vegetables in greenhouses, grains (corn, soybeans, wheat, barley, oats and canola), horticulture ornamental (Christmas trees, greenhouse, nursery and lawn) field vegetables, apples, potatoes, grapes and maple syrup (Government of Quebec, 2022).

The study area is located at the state level in the interior of the province of Quebec, Canada. The target population will be the owners or managers of agricultural machinery with the intention of enabling projects to automate conventional equipment on farms, and thus wish to have a property with faster and more agile general control resources.

GROWING SEASON

To define the level of annual use, the definitions of the growing season were considered, which refers to the longest constant period of the year in which temperatures are non-freezing, that is, greater than or equal to 0°C. In Quebec it lasts 5.7 months (172 days), starting on April 28th and ending on October 17th (Cedar Lake Ventures, 2023).

COSTS AND REVENUE

The costs were surveyed and evaluated to analyze the feasibility of implementing the automated system in tractors for agricultural crops predominant in the province of Quebec, referring to the main models of tractors used in the studied region.

Thus, evaluating the factors that generate the most unnecessary costs in automated processes, which are human issues (idle machine time - bathroom, lunch, coffee, etc.) defining the main costs inherent to the use of tractors in different applications in the studied region.

An important analysis was regarding the industrial market components most used in the industrial systems of Quebec companies, demonstrating greater ease of enabling time and costs for implementation in the field, thus being the data collection instrument. Due to the knowledge and experience in the automation engineering sector, the following paths were decided for the concept and development of the project, which is being applied to the same concepts in projects commonly used in industries in the studied region and the use of technological components at the same level of automation. For machinery costs, the John Deere 6120E model tractor was used with an approximate acquisition value of CAD 108,000.00 (Market Book, 2023).

DEPLOYMENT COSTS

The constitution of implementation costs was related to the tasks of implementing automation in tractors: estimated cost of engineering development (including programming work software, electrical drawings, startup). For the cost of implementation and engineering development based on the cost of the tractor at 40% (Eby, 2017), which is CAD 43,200.00. and for the total cost of components to be installed on the automated tractor CAD 67,674.00.

FUEL COSTS

The average fuel consumption of a walk-behind tractor can vary significantly based on a number of factors, such as the type of tractor, engine size, workload, terrain conditions, and even the specific design of the vehicle. Therefore, it is difficult to provide an exact average consumption figure. On average, traditional diesel tractors can consume between 5 and 20 liters of fuel per hour, but autonomous tractors, especially those with more advanced and efficient technologies, can have a different consumption range.

A utility tractor for use on small agricultural properties in the region, brand John Deere model 6120E, was used for the study, with the cost of diesel oil being CAD 40.41 h^{-1}, when determining the average consumption of diesel oil (21.38 L h^{-1}), achieved by considering its maximum power of 120 hp (88 kW), which fuel consumption is calculated according to the portion of energy requested by the equipment (kW h^{-1}) in operations and using the rate standard average 0.243 to estimate the fuel required, with the concept that agricultural equipment usually works at an average rate of 55% of its maximum power (Kamphorst, 2003). The price of diesel oil charged in the region was CAD 1.89 L^{-1}, on October 3, 2022 (Global Petrol Prices, 2022).

MAINTENANCE COSTS

Maintenance costs include the cost of replacement parts, repairs and periodic maintenance services. Replacement parts can represent a significant portion of costs, this includes items such as filters, belts, blades, bearings and other parts that need to be replaced regularly or occasionally. Investing in preventative maintenance can help avoid major repairs in the future. This includes regular adjustments, inspections and services to keep the tractor in good working order, preventative maintenance will be carried out daily through the inspection method, which is around 30 min per day, which will be carried out by the technician. Maintenance will be carried out in both conventional tractor and automated tractor study cases, as both agricultural machines will be the same model.

Maintenance also involves labor costs for carrying out repairs, changing parts and general services, taking into consideration, that the machine will have 100% availability within 24 hours considering setup stops following procedures and work instructions, which will be in around 20% of the total time of the day (4 h) and maintenance stops will be around 15% (3.6 h). Taking into consideration, that a technician will work an average of 4 hours per day on the machine and that his salary is CAD 19.50 h-1 in the period of 7 days that he works 40 hours per week, we will have a cost of CAD 546 for specialized maintenance appointments (Jobillico, 2023).

Items such as engine oil, transmission fluid, hydraulic fluid and other lubricants need to be changed regularly to ensure the good functioning of the tractor based on 500 hours of operation, as described in the manufacturer's specifications shown in Table 1 below (Deere & Company, 2023).

Tire maintenance costs must also be considered, as shown in table 2 below:

Wheels	Model	10.000h	Cost (CAD)
Traction	460/85/r36	x	815,00
Direction	320/85/ R22	x	700,00
Total			1515,00

Table 2. Component maintenance costs - wheels

Source: Original research data

Operating costs are described in Table 3, detailing cost estimates according to work periods.

Scientific Journal of Applied Social and Clinical Science ISSN 2764-2216 DOI https://doi.org/10.22533/at.ed.216482423043

Component	Technical description	Quantity	500h	1000h	5000h	Cost (CAD)
Engine oil	SAE 10W-40 PI Service Category CJ-4, CI-4, CH-4	15 liters	x			1080,00
Oil filter	model RE504836	1 unit	x			40,00
Transmission oil	Transmission/hydraulic fluid type - Hy-Gard 2, JDM J20C, JDM J20D	58 liters		x		350,00
Hydraulic fluid filter	SJ11792	1 unit		x		325,00
Primary engine air filter	SU20768	1 unit	x			117,00
Secondary air filter	RE253519	1 unit	x			36,00
Primary Diesel Oil Filter	RE551507	1 unit	x			60,00
Secondary Diesel Oil Filter	RE551508	1 unit	x			50,00
Cooling liquid	Prestone- 50/50-Premixed	19.1 liters			x	174,00
Total						2232,00

Table 1. Maintenance component costs - filters and fluids

Source: Original research data

Estimated operating costs	1 day; 16H (CAD)	1 week 112H (CAD)	1 Month, 448H (CAD)	6 months 2688H (CAD)
Diesel oil cost	646,53	4.525,72	18.102,87	108.617,24
Engine oil cost	34,56	241,92	967,68	5.806,08
Oil filter	1,28	8,96	35,84	215,04
Transmission oil	5,60	39,20	156,80	940,80
Hydraulic fluid filter	5,20	39,20	156,80	940,80
Primary engine air filter	1,87	13,10	52,42	314,50
Secondary air filter	0,58	4,03	16,13	96,77
Primary Diesel Oil Filter	0,96	6,72	26,88	161,28
Cooling liquid	0,56	3,90	15,59	93,54
Technical maintenance cost (3.6h per day at 19.50)	78,00	546,00	2.184,00	13.104,00
Setup cost (4 hours per day at 15.50)	61,80	432,60	1.730,40	10.382,40
Cost of operation (16h a day to 19,50)	312,00	2.184,00	8.736,00	52.416,00
Annual insurance 15 000,00$	41,67	291,67	1 250,00	7.500,00
Tires and wheels	2,42	16,96	67,87	407,23
Total	1.193,03	3.828,26	15.396,41	92.378,44

Table 3. Automated tractor operating costs

Source: Original research data

COST UPDATES OPERATORS AND AUTONOMOUS MAINTENANCE

The costs of training and supervising operators, or maintaining the autonomous system were defined through courses offered by the manufacturer of the components used to design the automated tractor system, shown in Table 4.

Type	Description	Quantity (h)	Value (CAD)
Allen–Bradley Formation	AB programming training	40	5.000,00
Additional training	Various training ethernet network supplementary modules	120	10.000,00

Table 4. Operating costs of the automated tractor

Source: Rockwell Automation, 2023

DEPRECIATION COSTS

Although it is not a direct maintenance cost, the depreciation of the tractor's value over time must also be considered, as it refers to the reduction in value or productive efficiency, caused by wear and tear, nature or technological obsolescence. To calculate depreciation, estimated useful life values in years and hours are required. Depreciation is assessed as a linear function of the useful life of the asset. According to the National Supply Company [Conab], a tractor such as the one considered in this study has a useful life of 10 years or 15,000 hours, using the percentage of 20% decrease per year in relation to the acquisition value, thus calculated for the period of growing season of 10% with a value of CAD 10,800 (Conab, 2010).

REVENUES

Based on the corn harvest revenue database for the periods between 2019 and 2022 from the Center for Socioeconomics and Agricultural Planning [CEPA], with information and estimates of corn production acquired over a period of one year for the project analysis basis, the cash flow for the period under study was determined in order to demonstrate productive efficiency with the use of a conventional tractor for a 50-ha property (CEPA, 2022). The price of corn varied depending on the class of industrial use shown in Table 5 and corrected by the interest rate defined by the Central Bank of Canada of 5% (Bank of Canada, 2023).

Price per bag	Yearly average CAD/ sack (CAD on 02/09/23)
2019	9,13
2020	13,72
2021	24,60
2022	23,07

Table 5. Corn price adjusted to interest rate Central Bank of Canada in 2022

Source: Original research data

CASH FLOW

Cash flow is equivalent to a methodology that demonstrates the values that change the cash balance, thus displaying a series of inflows and/or outflows of monetary values over a defined period of time (Gitman, 2003). For its disposal, constant revenues and expenses were conceptualized, which monetary estimates do not use the future correction of values in function of inflation.

A Minimum Attractiveness Rate [MAR] of 19.97% p.a. was used. for this work, taking into consideration, the Canadian inflationary scenario of 3.3%, thus using the sum of the interest rate defined by the Central Bank of Canada of 5% (Bank of Canada, 2023) and a tax burden from the province of Quebec of

14.975%, which is made up of the following taxes: Good and Services Taxes (GST) of 5% and the Québec Sales Tax (QST) of 9.975% (Revenu Québec, 2023).

The project was evaluated under two situations for tractor use: without automation and with automation.

ECONOMIC INDICATORS

The items contained in this study were composed and ordered in cash flow format using electronic spreadsheets, in which the economic indicators of the project were evaluated.

NET PRESENT VALUE [NPV]

Net present value is a capital budgeting technique that conceptualizes the value of money over time. Which discounts the project's cash flows at a rate that is equivalent to the minimum return that a project needs to offer to be considered (Gitman, 2010).

When applying NPV, both cash inflows and outflows are measured in monetary values. The following acceptance-rejection decision criteria are: if the NPV is greater than 0, accept the project or if the NPV is less than 0, reject the project (Gitman, 2010).

NPV is NPV is equal to the present value of the cash flows generated by the project, discounted at the rate, minus the project's initial investment (Gitman, 2010). The NPV calculation is presented in equation (1):

$$VPL = \sum_{t=1}^{n} \frac{FC_t}{(1+i)^t} - I_0 \quad (1)$$

where FCt: is the cash flow in the period t; I_0: is the initial investment; i: is the interest rate; t: is the period of time analyzed; e, n: is the number of periods.

INTERNAL RATE OF RETURN [IRR]

The internal rate of return is probably the most used of the capital budgeting techniques. The IRR is equivalent to the discount rate that makes the NPV of an investment equal to 0 (since the present value of the cash inflows is equal to the initial investment). In mathematical concepts, it is the rate i that makes the NPV zero. The following acceptance-rejection decision criteria are: if the IRR is greater than the cost of capital, accept the project or if the IRR is less than the cost of capital, reject the project. Such criteria ensure that the company receives, at least, the requested return (Gitman, 2010). The IRR calculation is described in eq. (2):

$$0 = \sum_{t=1}^{n} \frac{FC_t}{(1+i)^t} - I_0 \quad (2)$$

where FCt: is the cash flow in period t; I_0: is the initial investment; i: is the interest rate; t: is the period of time analyzed; e, n: is the number of periods.

PROFITABILITY INDEX [IL]

The profitability index is determined by the present value of future cash flows divided by the initial investment, which measures the value generated per real invested. It is similar to NPV, but with greater importance in situations where capital is lacking, it makes sense to allocate resources where the IL is higher. IL is also known as cost-benefit ratio, it is calculated by dividing the present value of inputs by the initial investment (Gitman, 2010). The IL was achieved from eq. (3):

$$IL = \frac{\sum_{t=1}^{n} \frac{FC_t}{(1+i)^t}}{I_0} \quad (3)$$

where FCt: is the cash flow in period t; I_0: is the initial investment; i: is the interest rate; t: is the period of time analyzed; e, n: is the number of periods.

The IL can also be displayed as a percentage (%), as in eq. (4), and which refers to the additional rate of return on the investment over the useful life of the project:

$$IL_{\%} = (IL - 1) * 100 \quad (4)$$

ADDITIONAL RETURN ON INVESTMENT [ROIA]

ROIA is the best estimate of profitability for analyzing an investment, composing in percentage terms the wealth conceived with the project, that is, it is what remains in percentage of return made available by the project over the required rate (minimum attractiveness rate [TMA]). The ROIA comes from the rate equivalent to the IL for each time interval of the project (Nogueira, 2016). In eq. (5) the ROIA calculation is described:

$$ROIA = ((1 + IL_{\%})^{\frac{1}{n}} - 1) * 100 \quad (5)$$

where ROIA: is the additional return on investment; IL%: the profitability index in percentage for the period; and, n: is the number of periods.

PAYBACK DISCOUNTED

The investment restoration time or payback is the number of fundamental periods for the return of values to exceed the money invested (Souza and Clemente, 2008). The discounted payback is the fundamental range for return on investment, taking into consideration, the present value of the period (Lapponi, 2007). The discounted payback calculation was obtained using eq. (6):

$$I_0 = \sum_{t=1}^{n} \frac{FC_t}{(1+i)^t} \quad (6)$$

where FCt: is the cash flow in period t; I0: is the initial investment; i: is the interest rate; t: is the time to recover the initial investment; e, n: is the number of periods.

SENSITIVITY ANALYSIS

Each estimated data (unit price, unit cost, initial cost, among others) to construct the project's cash flow is the closest possible or expected number. However, future numbers will be uneven, as there will be errors in the values prepared. Likewise, the produced cash flow and NPV indicator numbers will also become unequal to the expected assumptions. The occasion of these inequalities is what qualifies the project's uncertainty, and the dimension of these inequalities is what qualifies the project's risk, which is why sensitivity analysis is used as a methodology for assessing business risk, through the study of crucial aspects of the project (Lapponi, 2007).

The data analysis methodologies will be through the preparation of tables and cost comparisons, using updated budgets from reliable suppliers in the industrial region of Quebec.

RESULTS AND DISCUSSION

SYSTEM WORKING PRINCIPLE

Using the concepts of technological solutions for improvements in agriculture, Precision Agriculture [AP], smart farms (or as known, Smart Farming) and automation engineering will be applied to demonstrate the system to be suggested for converting conventional tractors, from purely manual piloting with operators, for autonomous tractors, with pilots in the cockpit, but with management functions only. The propensity of this advancement of mobile robots and autonomous vehicles for application in various activities is driven by improving the effectiveness, streamlining and benefiting the use of farm resources, whether in implements or in agricultural operations (Hackenhaar et al, 2014; Thomasson et al, 2019).

In general, the operation will be similar to that of a Computer Numerical Control [CNC] machine, the idea of which will be to control the tractor's direction through a servo motor coupled to a synchronized pulley transmission system directly to the steering wheel of the tractor. even, thus allowing steering control. To control the distance traveled, encoders will be attached to the tractor's wheels, so that they will be responsible for converting the rotation of the wheels into linear distance traveled. This linear information will be used to determine the position of the tractor in its specific workstation and position in the assisted field, called the work area. The work area will be square or circular in shape, with a distance of up to 1 km from the control center.

Communication from the control center to the automated tractor will be via WiFi system, so as to avoid the need to use geolocation, a technology that is not yet completely safe for implementation in different locations, thus becoming ineffective at certain times. This system provides significant information so that you can monitor the integrity of the machine, increase management availability, improve the flexibility of decision-making and increase safety, in addition to reducing the final cost of harvesting or other actions.

MOTION AND DIRECTION CONTROL

Automatic guidance systems differ in positioning accuracy depending on the positioning technology being used. They also differ in the level of control, which varies from light bar guidance to pilot control in the cockpit, automatic control on the steering wheel or fully automatic control without human interference. All major tractor manufacturers offer some form of automatic guidance, and systems are also available from companies that specialize in tractor guidance. However, available commercial guide systems still require some level of human intervention (Thomasson et al., 2019).

The steering control system will be made possible through the installation of a servo motor from the manufacturer Allen-Bradley [AB], in order to minimize interference with the original configuration of the tractor to be implemented with the autonomous system. It can be installed on all conventional tractor models. Therefore, to maintain steering control precision, the steering wheel will be equipped with a synchronized pulley transmission system so that it is directed according to the information sent from the control center. With configurations already analyzed and programmed to carry out the work in the most effective way possible. The servo motor ensures the positioning of the steering wheel axis through precise control, the following path of the tractor will be guaranteed in the turning of the steering wheel. This AB servo motor installation is intended to be an economical means of equipping tractors with the necessary dynamism and helping to advance the goal of smart working (Allen-Bradley, 2020).

As observed in the application by Porto (2015) with the reading of sensors and signal processing with the PLC, it demonstrates the purpose of choosing the application of servo components by function, the precise electronic control of the rotation and torque of the servo motor through information sent by the Programmable Logic Controller [PLC] Logix platform system, achieving agility and optimized control of the tractor steering wheel (Allen-Bradley, 2022).

For all steering control of the servo motor, information on the position of the tractor and its wheel is mandatory, this is done through the encoder coupled to the wheel. This component has the function of converting information from tire rotations (circular section) to lines (linear section) and sending a digital signal to the PLC that will have precise information about the tractor's position, as Raupp (2012) demonstrates with the controller reading the wheel position sensor to control the vehicle. The AB encoder provides accurate speed and position bases, optimizing the effectiveness of the entire Allen-Bradley system (2016). The AB 842E line component is a high-resolution absolute type encoder with EtherNet/IP interface, providing 18-bit single-turn resolution and 30-bit multi-turn resolution. However, the main point for choosing it is due to its high performance, reliability in adverse environments, and because the absolute type has the advantage that in the event of a power loss, positioning information will not be lost. (Allen-Bradley, 2016).

ELECTRONIC CONTROL SYSTEM

The system will be controlled by a PLC that will have the function of processing all information and programming received from the command center. The component applied will be from the Compact GuardLogix® series, as it demonstrates excellent performance, capacity, productivity and safety for this application. The 5069-L306ERMS3 PLC is SIL 3 classified and capable of implementing a safety task in addition to the other 31 standard control tasks. AB controllers use an easy-to-use work and development environment, as they have good integration between the programming software, Studio 5000 Logix, and the Input and Output [I/O] modules, drastically reducing the development phase, the cost in implementation in turn and making the operation viable. The compatible programming is the most common in the automation market, namely: Ladder Diagram [LD], Structured Text [ST], Function Block Diagram [FBD] and Sequential Function Chart [SFC] (Allen-Bradley, 2022).

Feature in the communication interface used Ethernet ports that can be connected to linear, star and device level ring [DLR] topologies at communication speeds of 10 / 10 / 1000 Mbps. The "Universal Serial Bus" [USB] 2.0 port can be used for local programming, configuration, firmware update and online adjustments, a feature of high application in field maintenance, quickly and simply, making it possible for technicians to work in any position of the tractor on the farm. This port supports a processing rate of up to 12 Mbps. Finally, the last important feature for choosing the PLC was the I/O capacity of 128,000 packets/second with a quality message rate of 2000 messages/second, these communication features which promote good operator safety in the cabin and externally of the tractor, as it is accurate when processing data on the actual positioning of the equipment in the field (Allen-Bradley, 2022).

Point I/O will be used to communicate with the PLC physically and send input and output signals quickly. Porto (2015) demonstrates the execution of recognition for each sensor or other operators through the I/O point of communication with the CLP. We will use digital and analog input and output cards to control the tractor's peripherals, such as acceleration, braking and operating modes such as engaging and disengaging the harvester. Safety inputs and outputs are installed directly on the tractor to be quick to respond to changes. occurrences. As stated in the technical manual Allen-Bradley (2022), the reasons for applying modular systems can be listed as follows: independently selecting the I/O and network interface; simple and agile installation and uninstallation, facilitating preventive and corrective maintenance; removable wiring allowing time for installation and adjustment of possible faults; general analyzes and configurable functions come from the application of POINT I/O; removal and insertion with the system powered and in operation; horizontal or vertical installation with the same dimensions, without changing capacity; possibility of automatic replacement using a portable electronic analyzing device (ADR) drastically reduces machine downtime; add-on-profiles in Studio 5000 Logix Designer® programming software contain full integration and easy programming; and most importantly for field application, protection against aggressive environments.

The entire system will be connected via a local WiFi network, controlled via a Human Machine Interface [HMI] where it will be possible to view the position and status of the machine, also making changes to the route directly by the operator inside the cabin, without the need for intervention from the operator. command center. This equipment will visually display the tractor's work program, displaying routes and other important information to the operator, as shown in Figure 1 below (Thomasson et al., 2019).

Figure 1. Example of work on the IHM and the control center computer

Source: Thomasson et al. (2019)

TRACTOR COMMUNICATION - CONTROL CENTER

Communication between the control center and the automated tractor will be via a WiFi system, considered an IoT system for this implementation. So, antennas will be physically installed at strategic points in the field and on the tractor. Choice of using WiFi with EtherNet/IP™ network protocol, as it provides systems with standard network technologies in the industrial sector. Enabling real-time control of a continuous process, such as field application, harvesting, sowing and others, and mainly for the reason of accurately identifying the position of the tractor in any area of coverage of the antennas, as also described by Jesus et al (2021) when defining the application of IoT for transport networks. Another very useful function for application in the field is the support for communications that are not necessarily industrial using a common network infrastructure. One of the main reasons for choosing the WiFi system is that the geolocation system is not yet available in many locations, thus becoming ineffective at certain times.

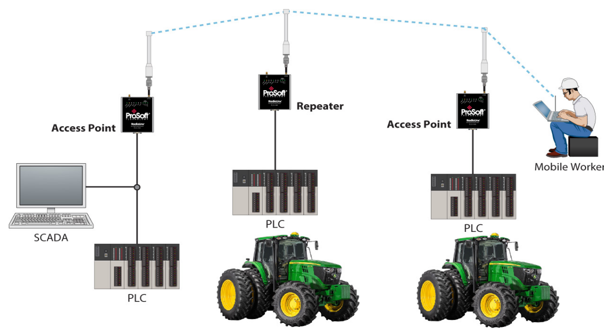

Figure 2. Network example - PROSOFT components

Source: Pro Soft Technology, Inc. (2022)

SECURITY

Regarding safety, we will use area scanners attached to the tractor, where these scanners are safety sensors responsible for detecting the presence of danger or human interference during automatic operating mode. Security will utilize pre-configurable area scanner sensors in order to reduce damage, detect solid objects such as logs in the path of the equipment, and most importantly detect people in the path of the tractor.

All components used were defined through technical consultations in their manuals, which determine the correct application for each characteristic relevant to the system.

BENEFITS OF OWN AUTOMATION

To be commercially possible, automated robotic systems [ARS] need to expand productivity based on current levels, having to respond quickly in unstructured agricultural environments. Technical factors that disrupt ARS include failures in detection performance and automated decision-making, along with the need for low human involvement in the work environment, mitigating production risks.

Thus, for implementation in the agricultural sector, these new technologies imply the use of techniques, mathematical studies through artificial intelligence and process improvement through analysis of sensors and images obtained in the field. All of these new methodologies have the main function of assisting in as many agricultural processes as possible, meteorological monitoring, genetic advances, developing irrigation methods and diagnosing the appearance of biological pests (Thomasson et al. 2019; Vasconcelos, 2018).

The project adds value to several functions for the producer with the use of Allen-Bradley components, as their strategy is to enable the technical implementation of projects, as it allows the stipulation of a commercial price and engineering time. AB components are programmed in a high-level language, allowing control and safety logic to be programmed with high efficiency and agility.

However, the benefits of automation will be demonstrated with the economic viability analysis of systems without automation and with automation.

ECONOMIC VIABILITY OF THE PROJECT WITHOUT AUTOMATION

Based on the cost analysis obtained from the conventional tractor and the production revenue base from the 2019 to 2022 CEPA harvest period, with information and production estimates acquired over a period of one year for project analysis, the cash flow of the period under study as shown in Figure 3.

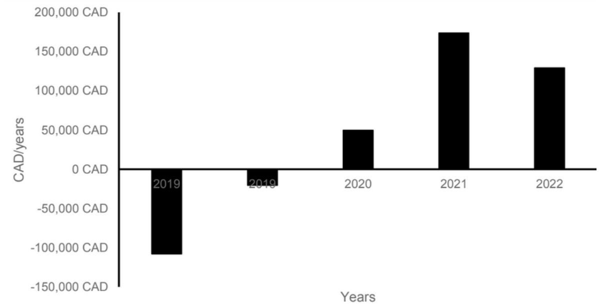

Figure 3. Cash flow of the tractor project without automation

Source: Original survey results

With this database and cash flow estimates, the economic indicators composed in Table 6 were determined.

Economic indicators	Expected values
Net present value [VPL] (19,97%)	72.543,69 CAD
Internal Rate of Return [TIR]	67,82%
Profitability Index [IL]	1,49
Profitability Index in Percentage [IL%]	48,88%
Additional Return on Investment [ROIA]	22,01%
Payback discounted	2,45

Table 6. Economic indicators of the tractor project without automation

Source: Original research data

Using the requested MARR of 19.97% p.a., the positive NPV equivalent to CAD 72,543.69 demonstrates that it is possible to be accepted, carrying out the project to use the tractors without automation. The NPV is described as a single monetary value calculated on the initial date, an attribute that presents difficulties when it comes to long-term projects (Souza and Clemente, 2008). As the authors say, there is another NPV analysis for each period, so that the judgment becomes easier due to the similarity in the concept of profit obtained per period. However, in order to decide on a project, it is necessary to analyze other indicators.

The IRR (67.82%) was higher than the TMA (19.97% p.a.) demonstrating that the project generated value. When validating the project's risk, the IRR is slightly different from the MARR, demonstrating a low-risk project in terms of financial return on corn production. This value was shown to be above the MARR as the IRR above the opportunity cost rate obtained by Müller (2014).

Still referring to profitability indicators for validation, the IL achieved was 1.49, that is, for every CAD 1.00 used in the investment, CAD 1.49 was recovered. By calculating the IL%, a real profitability of 48.88% in the post-harvest period was shown due to the rate of 19.97% per year. As demonstrated by Müller (2014) with positive profitability indices.

The period analyzed also demonstrated an ROIA of 22.01%, so that it was possible to recover just above 19.97% p.a. expected opportunity cost. This ROIA indicator improved the evaluation of the harvest period studied.

However, when validating the discounted payback risk indicator in the study period, it was demonstrated that in a period of 2.45 periods, that is, close to two years and six months after the investment, the cash flow becomes positive.

After the analysis under deterministic conditions, a sensitivity analysis was carried out in order to assess the project risk. Therefore, the effect of productive efficiency on the NPV of cash flow was measured (Figure 4).

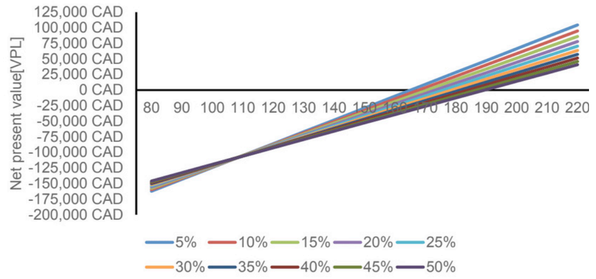

Figure 4. Sensitivity analysis varying the TMA and productive efficiency of the tractor without automation

Source: Original survey results

After evaluating the efficiency scenario of the tractor without automation, scenario analyzes were carried out increasing the price paid per bag produced, the value used in Figure 4 of CAD 40, so that a return on investment occurs more quickly, thus also changing the minimum attractiveness rates with the number of bags produced to validate the efficiency of the tractor and that costs are reduced over time. The project demonstrated a need to add value to the price of the final product so that the investment is recovered in less time.

ECONOMIC VIABILITY OF THE PROJECT WITH AUTOMATION

In order to validate the effect of automating the tractor during the study period, the cash flow for the period from 2019 to 2022 was investigated, as shown in Figure 5.

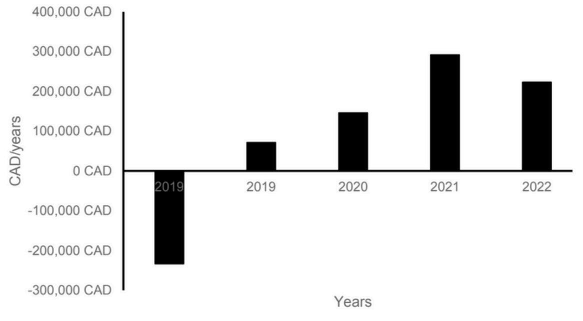

Figure 5. Tractor project cash flow with automation

Source: Original survey results

The project's economic indicators are shown in Table 7.

Economic indicators	Expected values
Net present value [VPL] (19,97%)	204.532,58
Internal Rate of Return [TIR]	82,88%
Profitability Index [IL]	1,14
Índice de Lucratividade em Percentual [IL%]	14,35%
Additional Return on Investment [ROIA]	6,93%
Payback discounted	2,05

Table 7. Economic indicators of the tractor project with automation

Source: Original research data

As demonstrated in Table 7, through the analysis of the TMA at 19.97%, an NPV of CAD 204,532.58 is observed with the automation of the tractor, which represents an increase of 182% in the NPV of the conventional tractor, equivalent to an increase in productive efficiency of CAD 4,090.65 per hectare.

Regarding other indicators, there was an increase in the numbers compared to the tractor project without automation. Müller (2014) shows an IRR above the attractiveness rate to validate the project, at a rate of 82.88% obtained with the automation of tractors, it was well above the TMA, denoting that the project with automation must be accepted.

Just like the profitability index above 1 found by Müller (2014), the validation of the IL evidenced was 1.14, that is, for every CAD 1.00 used in the plantation, CAD 1.14 would be recovered, or simply, it would be purchased CAD 0.14 for every CAD 1.00 invested. And as for IL%, it showed an expected real profitability of -14.45% in the period studied. Demonstrating that it is unfeasible to automate tractors in a first analysis of just profitability.

The period analyzed also demonstrated an ROIA of 6.93%, so that by redeeming the 19.97% p.a., an additional return was achieved below the MARR.

Finally, when evaluating the discounted payback risk indicator in the study period, it was shown that in a period of 2.05 periods, which means, in a period of just over two years after the investment, the cash flow becomes positive and returning the value of the investment.

Following the analysis under deterministic conditions, a sensitivity analysis was carried out to investigate possible project risks. Therefore, the effect of productive efficiency on the NPV of cash flow was estimated (Figure 6).

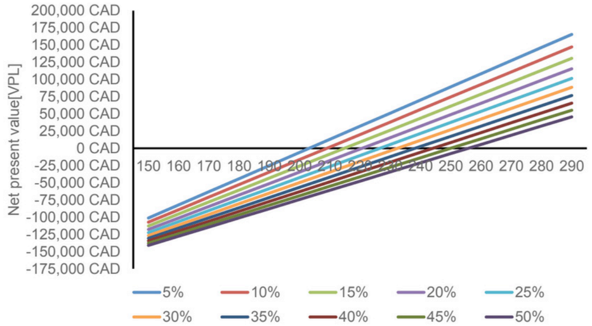

Figure 6. Sensitivity analysis varying the TMA and productive efficiency of the tractor without automation

Source: Original survey results

When evaluating the efficiency of the automated tractor, scenario estimates were made increasing the price paid per bag produced, the value used in Figure 6 of CAD 40, as in the tractor without automation, but greater productivity is possible with automation, therefore greater production validation. So that a return on investment can also be seen more quickly. Soon, the minimum attractiveness rates were also changed with the quantity of bags produced to legitimize the efficiency of the automated tractor and that other costs are greatly reduced over time and returned to the cash register in the form of productive revenue. The project demonstrated an intention to add value to the price of the final product with more efficient production and thus the investment is recovered in less time than a conventional tractor.

CONCLUSIONS

Automation proved to be viable in the scenario of using a tractor with automation, as production efficiency increased considerably and thus reduced the return on investment time.

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