[203027] Methodology for easing the deployment of cattle raising georeferencing tracing technologies on Colombian Farms. Case Study

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Abstract

The livestock sector is fitted with modern technology that has been developed and implemented in several countries. However, according to FEDEGAN, in Colombia, more than 65% of farms have a low technological level and the modernization of the sector is subject to considerable improvements applying georeferencing technologies. Therefore, this research project develops a methodology for the application of georeferencing technologies in the livestock sector of Colombia. The proposed methodology is based on concepts of Agile methodologies and develops 4 sequential stages that guide the Colombian farmer in the integration of these technologies to its farm. The initial stage identifies and characterizes the farmer's requirements, applying an adaptation of the Quality Function Deployment (QFD). According to the results, it is proposed the use of the Analytical Hierarchical Process (AHP) to select the device that matches the farmer's criteria. The second stage includes purchasing the proper device based on the previous stage's insights. The third stage guides the farmer in the testing of the device selected, and finally, in the fourth stage, a proposal of how to analyze the data obtained by the georeferencing device is presented. The results of the methodology were validated by an expert panel through a focus group, and by a case study.

Figure 1. Stages of the methodology proposed.
Source: Own Authorship

Key words: Cattle Rising, Industry 4.0, Cattle Rising Management, Livestock, Colombian livestock production, Georeferencing technologies.

1. Problem statement and justification

Colombia is a country where cattle raising production plays an important role in the economy. Cattle-raising is a branch of animal husbandry concerned with raising cattle for milk, beef, and hides. Historically, cattle raising has contributed 1,6% of the national GDP, approximately 20% of the agricultural GDP, and 53% of the livestock GDP (Maroso & R, 2013). Additionally, in 2018 there were 31 million hectares destined to this sector throughout the national territory (Corredor et al., 2018). The cattle-raising sector also has a social impact because it generates 810 thousand direct jobs, which represent 6% of national employment and 19% of agricultural employment (Federación Colombiana de Ganaderos, 2018). The importance and magnitude that the sector represents for the country claim a need to be more competitive and to present greater productivity.

According to FEDEGAN, the National Federation of Cattlemen, the number of farms used for cattle raising production in Colombia has increased around 27% between 2004 and 2019. This means that the number of farms destined for this purpose went from 491.305 to 623.794. If the country continues with the trend that the records show, in Colombia, there will be more land destined for livestock production. Additionally, disregarding deforestation, and considering the increasing rate above named, the real issue will be how to become more productive if there is a limit of available lands.

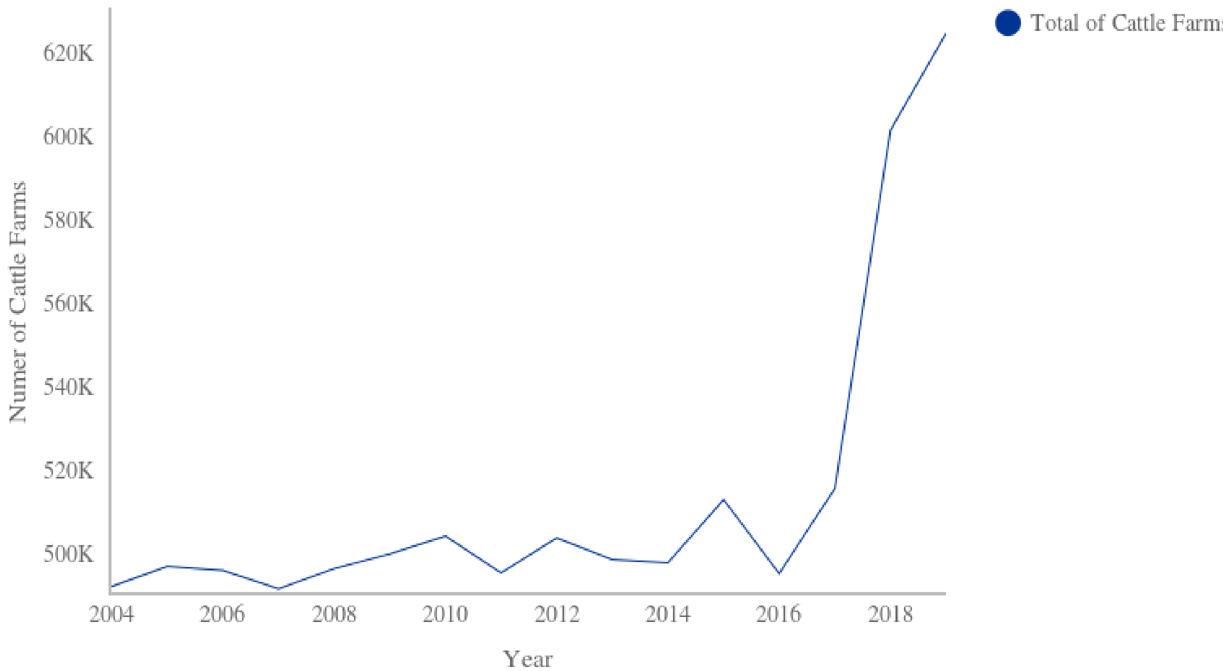


Figure 2. FEDEGAN, Statistics of Cattle Farms in Colombia
Source: FEDEGAN (*Federación Nacional de Ganaderos, 2019*).

The livestock production structure in Colombia is itself a major issue, this one consists of: Extractive (6,2%), traditional extensive grazing (61,4%), improved extensive grazing (3,5%), and confinement (less than 1%) (Arango, G. 2000, Pag. 89). Also, according to IGAC (Colombian Geographical Institute), the country had a major underusing of its productive land by the year 2005, this rate was showed by Cuenca, Chavarro and Diaz (2007) in the graphic below. With the facts mentioned above, it is clear to say that there is an opportunity in Colombia by making cattle raising management better.

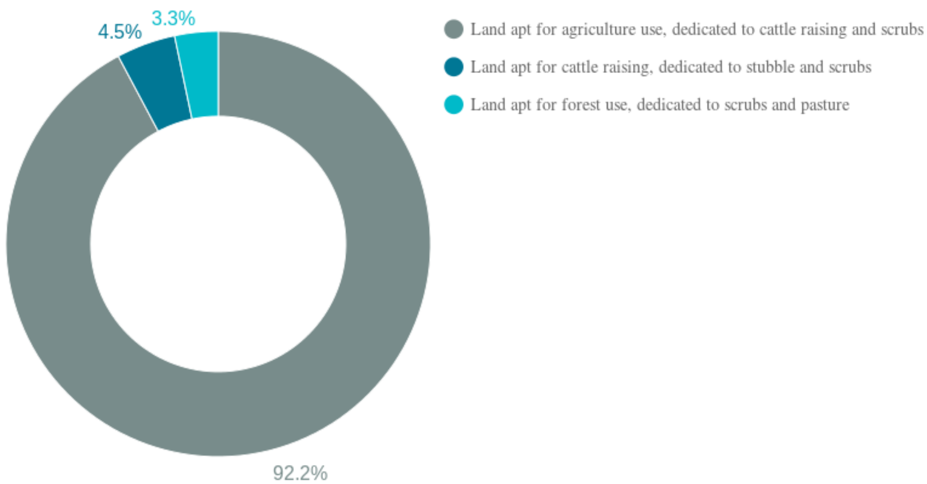


Figure 3. Land distribution with sever underusing (%). 2005
Source: Cuenca. N. Chavarro, F. Diaz, O (2007)

In today's world, there is a gap between countries with the application of the I4.0 technologies and those that do not have enough technological advance. Issues as grazing and monitoring livestock have become a necessity in recent years for security and information gathering concerns. The implementation of georeferencing GPS systems and drones with state-of-the-art cameras has allowed real-time monitoring of the cattle's path to use the location and movement as information derived from the data. Researchers have been able to determine the impact on the environment of animals, as well as how to evaluate animal responses to management activities or environmental disturbances using these technologies (Hikmah et al., 2016).

Additionally, matters as paddock distribution, recompilation of data as weight measure, stage of gestation, type of pasture, and being or not a floodable soil, make the problem of livestock production and the use of the land more complex. Farm management and making the pasture sustainable for the future, still being one of the challenges for livestock production. In this regard, Motta, Ocaña, and Rojas in 2019 searching on indicators associated with pastures sustainability, concluded that technics as silvopastoral or rational grazing are a significant advance in making efficient pasture management (Motta et al., 2019).

Particularly in livestock, the principal technologies implemented directly from I4.0 are georeferencing monitoring systems and drones that monitor pastures. The benefits granted can be obtained mainly in the management and administration of the farms. These benefits include management indicators and reduction in the time spent by workers on some daily works as counting the livestock.

Colombia has a delay in the implementation and use of georeferencing technologies in the agroindustry. These technologies have tremendous potential in terms of making the economic sector more efficient and easier to manage. Therefore, this study shows up how I4.0 technologies, specifically georeferencing technologies, can improve management processes. The impact of developing a method according to which farmers may take better decisions will be positive if the number of lands being underused destined for livestock production is analyzed. Finally, having the chance to measure the performance of these georeferencing technologies in a Colombian farm would not be only to pose a method but to teach a manner of improving the livestock sector. Therefore, the research question of this study is: “¿How a detailed methodology could help farmers to use georeferencing technologies from I4.0 on their farms to improve farm management?”

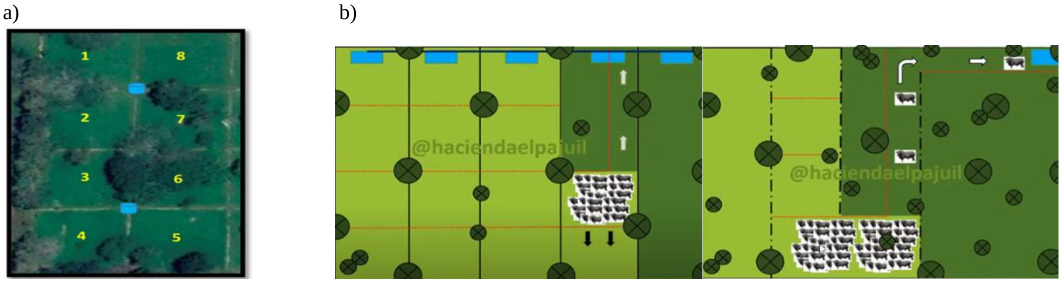
2. Background

This section presents studies on the livestock production field grouped into four perspectives. The first perspective includes management models in the cattle-raising industry, the second perspective includes the implementation of computer models in the management analysis. The third perspective provides information about GPS (Global Positioning System) and GLONASS (Global'naya Navigatsionnaya Sputnikovaya Sistema) technology, and the last one is related to the use of technology in the sector.

Livestock activity is a decision-making process, which involves planning, organizing, directing, and evaluating activities to achieve the expected results and, consequently its sustainable growth over time (González K, 2020). One of the most relevant issues is the distribution of resources, especially topics related to grazing, a scarce resource in the industry. In this regard, many administrative models have been developed to standardize processes and take decisions under theoretical and technical bases. Some of these propositions will be explained below.

One strategy to take advantage of pastures to increase efficiency is rotational grazing. The biochemist and farmer André Voisin raised a theory, where the key is to minimize the occupation time of pasture from one (1) to three (3) days maximum. The main objective is to avoid the consumption of sprouts in the same period of occupation, allowing the pasture to have a sufficient rest time to emit more spouts and with more reserves of protein (Mejia, S et al, 2019). According to Mejía-Kerguelén et al (2019), the recovery time varies depending on several conditions, for instance, the fertility of the soil, the dept of grazing, the distribution of rainfall, among others. Therefore, this grazing model points to the grouping of animals in small areas for short periods. In Figures 4(a) and 4(b) distribution of paddocks for rotations is shown.

a) b)



Source: Mejia. S et al, (2019) Source: Jiménez R. & Manrique. E (2020)

Figure 4. Rotational system of paddocks (a). In this figure, the numbers indicate the rotation sequence of the animals, and the blue rectangle is a drinker. PUAD rotational system (b). In this figure, the green circles with a cross are trees, the blue rectangles are drinkers, the black lines are fixed fences, the red lines are movable fences, and the white arrow indicates the way to the drinker.

A similar model is the PUAD (Ultra High-Density Grazing). The model suggests dividing the grazing day into hours of grazing, dividing the paddock into modules of up to 100 m2, and rotating the animals several times a day, allowing loads of up to 1.000 animals (Jimenez, R & Manrique, E, 2020). Figure 4(b) shows a diagram of the distribution of paddocks, with the red and black lines being electric fences and fixed fences, respectively.

Farm management depends on many variables and decisions that should be included to establish an optimal model. This matter concerns investigators and researchers of the field, who had developed and implemented computer models to resolve traditional problems and optimize current management strategies. The objective is frequently oriented to improving biological or economic performance and/or to mitigate the environmental impact (Bicknell et al., 2015). Some of the existing models may be grouped into two broad types: simulation models and optimization models.

Simulation is a technique frequently employed by practitioners who profess to be adopting a "system approach" or doing "system analysis" (Anderson, 1974). In a review made by Bryant and Snow (2008), simulation models are developed according to different objectives. Primarily, there are simulations of grazing systems, animal production, farm management, soil nutrient dynamics, crop, or pasture production, among others. A proper example of the application of simulation models in the livestock sector is a study carried out by Martin and Mange (2015). In this study, the authors simulate a farm system to evaluate the results of increasing the agricultural diversity, related with the potential for increasing adaptive capacity and reducing vulnerability against the weather variability.

Concerning optimization models, linear programming is commonly used as a quantitative analysis technique to determine the optimate resource combination. Most of the previous studies are oriented to achieve objectives as maximization of profits or minimization of environmental impact. (Paz, 1996), for instance, a study carried out in Costa Rica analyzing dual-purpose livestock with three approaches. The first one is the quantitative characterization of the farms, the second one is pasture management and the third one is the use of available resources for animal feeding. These objectives were oriented to the maximization of profitability. Other common approaches are the evaluation of nutritional components in the diet (Soto & Reinoso, 2011), the allocation of animals in the available paddocks (Vici et al., 2008), and the inclusion of sustainability in the pasture issue. (De Oliveira Silva et al., 2017)

Furthermore, recent studies and research have evolved to include devices and technology tools in the industry, supported in some cases, by computer models. In the pasture scope, Gobor et al. (2016) proposed a project integrating a pasture robot with software named I-LEED, to control the robot and provide calculations of the optimal feeding strategy and the maintenance of the pasture. Additionally, it is possible to implement an evolutionary algorithm to define the trajectory of the pasture robot, identifying the areas with weeds, cowpats, and without vegetation to generate feasible trajectories (Cariou & Gobor, 2018). In livestock management, ground robots are focused on biofuel and natural fertilizer production, but also in the process of rearing the animals themselves (Midilev et al., 2019).

Another issue that stands out frequently in the Colombian livestock industry is data collection. Smart computing including internet and cloud-based connectivity can be linked with physical devices for data collection and analysis (Neethirajan et al., 2017). The integration of technologies and artificial intelligence to digitally monitoring the agro-industrial sector is being carried out by companies like Hemav. They collect information through drones that grant an overview of plots with high-definition images, location maps, and digital surface models. Moreover, multispectral remote sensors allow generating maps of plant indices that can be interpreted as indicators of the state of pastures, nutritional quality, nutritional condition, water, or any other property. These multispectral sensors are coupled to drones allowing a greater number of observations and a better estimate of the availability and coverage of the pasture (Insua & Utsumi, 2018). In general, these techniques are based on a strong data gathering that supports its implementation. In this study, data gathering techniques are very important to collect reliable and relevant information about the processes.

Data gathered is handled with the implementation of different software to store up the essential information and to generate indicators. Tambero.com, for instance, is a completely free system that works on mobile phones or computers and allows the farmer to carry information about animals and crops. Once the basic information of the animals has been entered, recommendations for improvement are made based on scientific data and the use of best agricultural practices. Risc and Pérez in 2020, showed a series of steps that, using the software LoRa and LoRaWAN, allowed to select a cultivated area, identify crops with lower production and performance, measure parameters as climate, water consumption, or agronomic data, upload data to cloud servers and finally give the information to farmers through web apps. This proposal promises modern agroindustry in Perú, a country where crops and food production represent a relevant percentage of the economy (Risc & Pérez, 2020).

The implementation of navigation systems allowed real-time monitoring of the cattle's path, using location and movement. An example of the application of this technology is a project by Butler et al. (2006). The authors implemented the concept of a virtual fence, tracking the animal's position with a Smart Collar and applying sound stimulus when the cow goes behind the fence. A similar approach was proposed by Sickel et al (2004). The authors designed a methodology that uses aerial photos and GPS equipment mounted on a collar, to track cattle movements and to analyzed them with a vegetation map. GNSS (Global navigation satellite system) technology can be used to improve pasture management identifying grazing preference of the cattle and its behavior when pasture availability change (Manning et al., 2017), to create specific fertilizer recommendations from maps of pasture utilization (Trotter Lamb, D.W. et al, 2010), among others. Calcante et al. (2013) analyzed a model that includes a GPS collar and a transceiver, to identify when animals' delivery begins and informing the farmer via SMS (Short Message Service). An additional tool is radio frequency identification. This one was applied by Williams et al., (2019) to examine cattle visits to the water point in northern Australia. In this study, the authors included weather information and analyze the findings according to the stations.

As the use of GPS Technology in the livestock sector is recurrent, the understanding of its architecture is crucial. The architecture of GPS is composed of 4 segments. The first one corresponds to the space segment which includes the 24 satellites that send signals to the user. The second one is the control segment, which monitors and operates satellites, and it is run by the US Air Force. The third one is the user segment, which includes the hardware and software involved in positioning, navigation, and timing. The last one is the ground segment, which includes civilian tracking networks that provide the user segment with reference control and real-time services (Blewitt, 1997). An equivalent technology of the GPS is the GLONASS (Global Navigation Satellite System). This technology works like the GPS and its space segment consists of satellites distributed over three orbital planes. It has a ground segment, which ensures operation coordination of the entire system and consists of the System Control Center, the Central Synchronizer, and the Phase Control Center, which are all situated in Moscow. The user segment consists of the entirety of GLONASS receivers. These receive and evaluate the signals transmitted by the satellites (Roßbach, 2000). The last segment starts with the GPS or the GLONASS receiver, which takes the information from the satellites and uses triangulation to calculate the user's position and time using a microcontroller (Pozo Ruz et al., 2000). Then, the information is transferred through a wireless network like GSM (Global System for Mobile Communications), GSM/GPRS (general packet radio service), Wi-Fi (Wireless Fidelity), LoRa (Long Range Modulation), ZigBee, among others, and finally transmitted to a server (Ruiz, 2016). It is also possible to save the location information in a memory card and transfer the data throughout a serial port, however, in this case, a physical connection with a computer is necessary (Gorandi et al., 2015). The functioning of the GPS in the sector is shown in figure 5 in two different forms (Wireless and Passive).

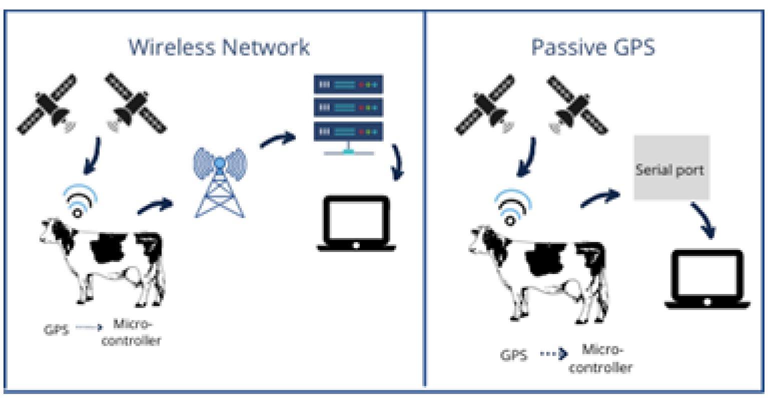


Figure 5: GPS Architectures for data collecting.
Source: Own Authorship

Considering examples in Colombia, a couple of farms have implemented the technology in their processes. The farm, El Encinar, for instance, is a farm located in the Valle del Cauca and focused on milk production. On this farm, all five days old calves receive a chip with a unique number of 15 digits for identification. The farm's operation is monitored by cameras connected to the internet 24 hours, and all the data related to tracking, security, and animal identification is saved in software that provides management indicators and real-time data (Contexto Ganadero, 2015). Furthermore, Colombian companies as Taxila, are working in the implementation of drones in the country's farms to optimize the analysis and data gathering for the sowing of grass, corn, among others. The use of drones to get images and information about the field is complemented with software to analyze it (Contexto Ganadero, 2017).

Considering examples in other countries, in the context of Lidia, Spain, an investigation of the social behavior of the cattle was carry out to prove the existence of a maternal-filial bond between mother (cow) and calves. In this study, the animals' position was tracked by a collar developed by ORANGE, and the distance between related and unrelated individuals was the source of the main results (Lomillos et al., 2016). Furthermore, digital technology adoption in Switzerland was studied by Groher et al., (2020). The results showed, on one hand, that dairy farms are the sector with a broader range of technologies available, and the most common are digital milk meter, transponder collar, milk flows sensor, and concentrate feed intake. On the other hand, farmers raising beef cattle, mostly implement transponder collar and electronic weighing systems. In Australia, for instance, Gargiulo et al. (2018) evaluated different adoption patterns according to herd sizes and found that larger farms adopt more precision dairy technologies and that by 2025 adoption of data capturing technology for monitoring farm system parameters would be increased.

Prior and useful studies have been identified after a detailed research about different methodologies, technologies and models applied to the livestock sector. It is possible to conclude that the main asset in the management of farms is the data collected. There is multiple software designed to store data in logic and organized structure, and the principal issue is related to the gathering and analyzing process of the information. Furthermore, the most common approach is the allocation of resources, including pasture, water, and feeding. To summarize, the technological solutions provided in the georeferencing field and another context of I4.0 have improved processes and indicators in the sector but have not been applied broadly in the Colombian context.

To categorize and summarized the information gathered related to georeferencing technology, the following table was designed discriminating technology, variables measure, purpose and structure followed to obtain data.

Table 1. Characteristics of georeferencing technologies

Technology	Variable	What is it for?	How?
Georeferencing	Geographical location (x, y)	To manage the farm, verifying the person in charge does the pasture rotations.	Through a digital map with points that shows the real time position of each cow.
	Maximum inactivity time (min)	It is possible to reduce the number of deaths and attend deliveries on time.	Detecting abnormal situations related to the usual behavior of animals: excessive movements or rest.
	Average distance travelled in a day (m)	Delimitation of grazing areas, and times of pasture change.	Through movement maps (heat) that identify excessive routes due to excess grazing space.
	Differential of occupied area (1.0)	Technology can be used to improve pasture management identifying grazing preference of the cattle to create specific fertilizer recommendations from maps of pasture utilization	Through heat maps detecting areas where cows accumulate to eat, these areas are identified as those with the highest nutritional contribution and quality.
	Geographical location (x, y)	Provide safety on animals.	Issuing an alert if the animal exceeds the limits of the farm.
	Differential of occupied area (1.0)	Fencing virtually sub-paddocks.	Delimiting a geographic grazing space and once established, the animals wear special collars that emit a beep or a small electric shock if they exceed that virtual space.
NOTE	With the same collar that serves as a unique identifier, information as weight measure, stage of gestation, number of vaccines to be applied, number of deliveries can be provided to be saved in the cloud as management indicators		

Source: Own Authorship

The information above provides specific approaches to the problem and summarize the variables that can be involved in this project. Particularly, the “Max average travel (m)”, the “Geographical location (x, y)” and the “Maximum inactivity time (min)”, are variables that intent to solve relevant issues in the industry mentioned before and could be the target variables of this project.

3. Objectives

Design a deployment methodology for cattle raising georeferencing I4.0-technologies, to ease the management and technological advancement in the cattle raising sector in Colombian farms.

For accomplishing this objective, it is necessary to follow the following specific objectives:

1. Characterize and select the georeferencing technologies, procedures, and devices of I4.0 that can be applied to the cattle raising sector in Colombia.

2. Develop a deployment methodology to integrate the previously selected georeferencing I4.0 technological tools on farms in the Colombian context.
3. Deploy the proposed methodology at *Hacienda La Secreta* farm through a pilot test, considering the more appropriate georeferencing tools for improving efficiency and productivity in their management operations.
4. Evaluate the impact of the deployment methodology on georeferencing I4.0 technological tools in Colombian farms, based on the experience working in the case study farm (i.e., *Hacienda La Secreta)*.

4. Methodology development

In this section, the process that was carried out to build the methodology to apply georeferencing technologies in the cattle sector is explained. This section is composed by the following phases:

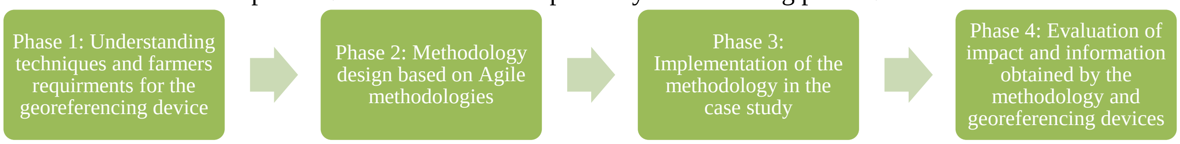


Figure 6. Phases of the methodology development

Source: Own Authorship

These phases were based on existing methodologies in Agile framework, for instance, SCRUM, Extreme Programming XP, and the Feature-driven development (FDD). For more information about the methodologies investigated look at Appendix 1.

4.1. Phase 1: Understanding techniques and farmers requirements for the georeferencing device.

In this phase, it is shown the understanding of the techniques that could be used to select the technology that fits the requirements and the necessities of the farmers. In the first place, it is presented the understanding of the Colombian farms necessities and problems to approach the context. In second place, a characterization and grouping of technologies. Finally, in the third place, a classification of devices to cross them with the farmers need.

4.1.1. Understanding of Colombian farms necessities and problems

The problems faced by Colombian farmers have been crucial for the analysis. In general, it was found that there are three main problems: The low competitiveness and productivity, the lack of appropriate nutritional decisions, and the number of farms that do not use semi-intensive supplemented and extensive improved systems for its management (Vergara, 2010). Also, studies propose some solutions for the named problems, these could be summarized in the next statement: Increase use of technologies at the farms will allow taking better administrative and operational decisions, which will be reflected in more competitiveness and productivity (Mahecha et al, 2002). The complete research can be found in Appendix 2.

According to the above statement, the use of innovative technology can be an appropriate strategy to improve the Colombian livestock industry. However, it is important to determine the appropriate areas to apply the technologies. Thus, it was decided to submit a survey, specifically an observational study, through state cattle federations with the objective of receive firsthand information from veterinaries, farm owners, and farm managers regarding the most critical issues that they face, to obtain a firsthand resume of opportunities. The survey was conducted among a total of 55 people and corresponds to a convenience sampling, due to the size of the population and the time limitations.

The analysis of the survey's results is the following: the average size of the farms evaluated is 370.7 hectares, and the average number of animals per farm is 400. These variables are positively correlated, which means that more hectares are equivalent to an increase in the number of animals on the farm. However, the number of paddocks on the farm and the number of animals per hectare have an inverse correlation, decreasing the stocking density per paddock in bigger farms. This could be explained due to lower nutrition levels of the grass because of sprouts consumption or fewer/inadequate fertilization. The size of the paddocks is not correlated with the number of paddocks, but as was expected, the size of the paddock is correlated with the animals per paddock. The average of animals per hectare corresponds to 14.4, which could be explained if the environmental conditions, soil fertility, and grazing system are considered. According to the results, the occupation days of the paddock are also correlated to the animals per hectare, in this case, if the days of occupation are less, the animals per hectare will increase. The mean of the variable days of occupation is 10 days (about 1 and a half weeks), results that are different from the theory of optimal grazing systems.

Some of the activities and situations that were identified on the farm as an issue, or an improvement opportunity are showed in the figure 7.

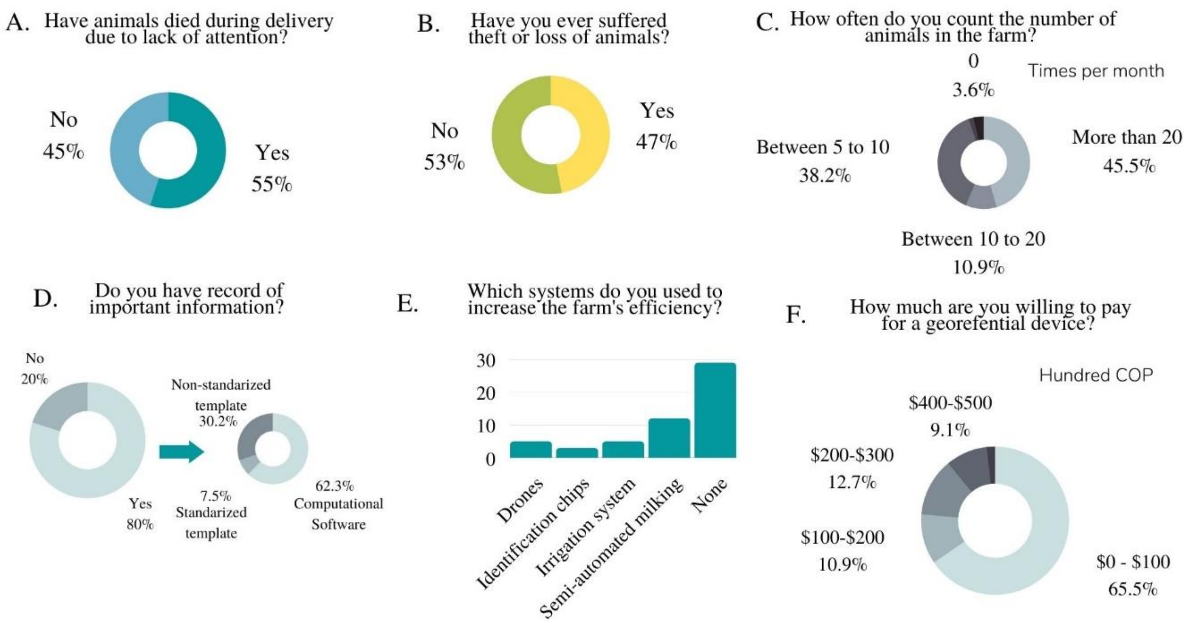


Figure 7. Survey relevant results
Source: Own Authorship

In general, there is evidence of the lack of technification in the farms (figure 7.E), the practice of inefficient activities (figure 7.C), and the occurrence of situations with a negative impact (figure 7.A, 7.B). The grazing system, for instance, has several improvement opportunities by implementing georeferencing devices. After data collection and treatment, it would be possible to determine certain areas of the paddocks that are not being used by the cattle and take measures about it. The implementation of electric shocks, to prevent the cattle from going outside the paddock area, would reduce the cost of installing and maintaining electric and traditional fences. Also, the average distance that cattle is walking could indicate lack or excess of food in the current paddock, and therefore, the ideal time to change the paddock and get ahead to unnecessary cattle weariness. Thus, the implementation of a georeferencing device could be a strategy that will have a real and positive impact on farms of the livestock sector, but it is necessary to consider that in general, there is no intention of the farmer on investing in expensive alternatives (figure 7.F). The Appendix 3 sets out the survey methodology and technical file, including the corresponding results and analysis.

4.1.2. Characterization of available georeferencing technologies and devices

The reception and growing popularity of the GPS (Global Position System) system and GLONASS (Global navigation satellite system) system, including the advances in cellular, radio, and satellite communications technology have prompted humanity to create and innovate in location systems. Its purpose is to monitor positions given by coordinates through the combination of the internet.

The georeferencing tracking system uses GPS or GLONASS with a combination of wireless networks to transfer data. Wireless network is a network through which data signals flow through the air. The transmitted distance can be anywhere between a few meters as a television's remote control and thousands of kilometers as radio communication (Sharma & Dhir, 2014). Regarding IoT technologies, one of the most important designing parameters of a communications network is the maximum range. Following, some protocols are discriminated by the working range and summarized in the figure 8.

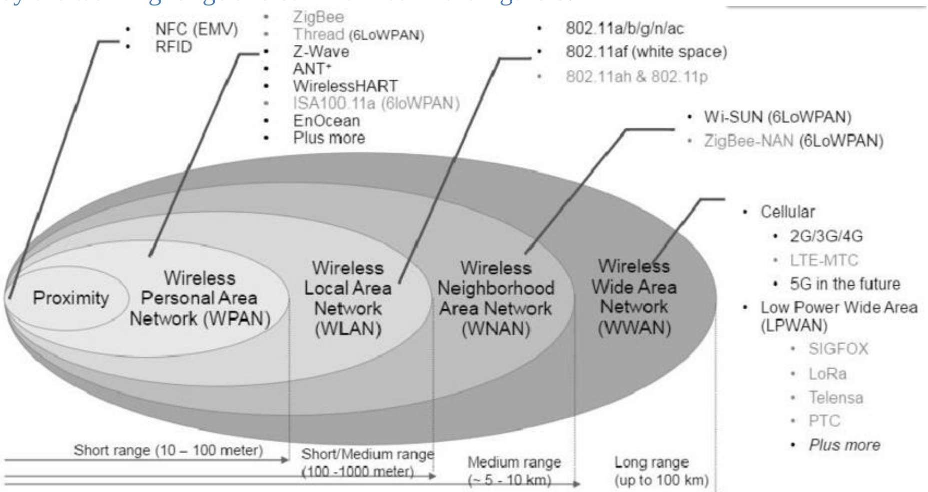


Figure 8. Summary of Wireless Networks for IoT according to Working rage
Source (Medina et al., 2018)

The Wireless Personal Area (WPAN) has a short range, between 10 to 100 meters, and includes for instance a) Bluetooth LE, with a maximum transmission rate of 1 Mbit/s and operating in the 4.5 GHz frequency band, b) ZigBee, used for applications that do not require high speed and in which there are power consumption limitations (Medina et al., 2018). ZigBee has a range of around 100 meters, a bandwidth of 250 kbps and the topologies that it works are star, cluster tree and mesh (Madakam et al., 2015). The Wireless Local Area (WLAN) has a short/medium range, between 100 to 1000 meters, and includes for instance, WiFi (Wireless Fidelity). In terms of GPS technology, the most frequent communication network is the Wireless Wide Area Network (WWNAN). These types of networks can be maintained over large areas, such as cities or countries, via multiple satellite systems or antenna sites looked after by an Internet Service Provider (Sharma & Dhir, 2014), and includes:

- Cellular
  - 2G/3G/4G: The Cellular Digital Packet Data is used for transmitting small units of data over a cellular network. The 2 Generation involves GSM (Global System for Mobile communications) and GPRS (General Packet Radio Service), characterized by a transmission rate between 12 to 55 Mbps and a maximum range of 100 km. It is the most used technology, but the wireless spectrum is limited.
- Low Power Wide Area (LPWAN): LPWAN offers multi-year battery lifetime and is designed for sensors and applications that need to send small amounts of data over long distances a few times per hour from varying environments (LoRa Alliance, 2015)
  - Sigfox: The system supports rural applications with working ranges between 30 to 50 km and in the case of urban areas from 3 to 10 km, the throughput is approximately 100 bps,

consumption is quite low which it hovers around 50 microwatts (Medina et al., 2018). The emitted message is received by any base stations that are nearby and on average the number of base stations is 3. Additionally, in order to address the cost and autonomy constraints of remote objects, Sigfox has designed a communication protocol for small messages. In the case of the GPS coordinates the upload size of the messages is 6 bytes. The Sigfox network is composed by 2 layers. The network equipment consists of bases stations in charge of receiving messages from devices and send them to Sigfox support systems, which is the second layer. This layer is in charge of processing the messages and send them through call backs to the customer system (Sigfox, 2017). Figure 9 shows the complete architecture.

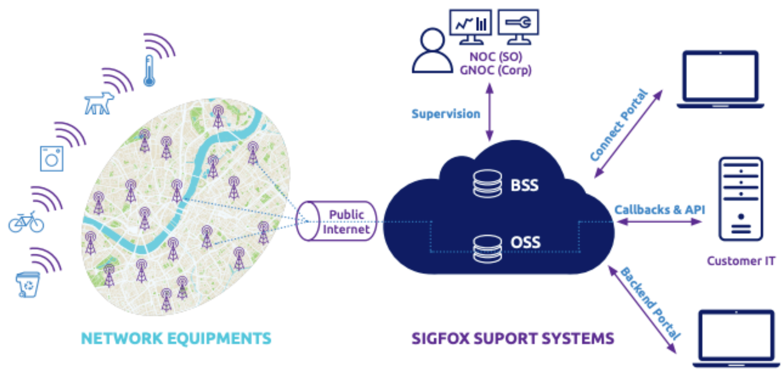


Figure 9: Sigfox's architecture
Source Sigfox (2017)

- LoRa. Long range technology with low power consumption. The objectives of this technology are to increase sensor battery lifetime and reduce the device cost. LoRaWAN defines the communication protocol and system architecture for the network while the LoRa physical layer enables the long-range communication link (LoRa Alliance, 2015). Unlike Sigfox, LoRa is an open network. The Architecture involves some segments, the End-devices (different sensor types) communicate to the gateway using LoRa/LoRaWAN RF interface. The gateway transmits frames to the server through a non-LoRaWAN network such as Ethernet, 3G/4G, Wi-Fi, etc (Bouguera et al., 2018). Figure 10 shows the segments involved.

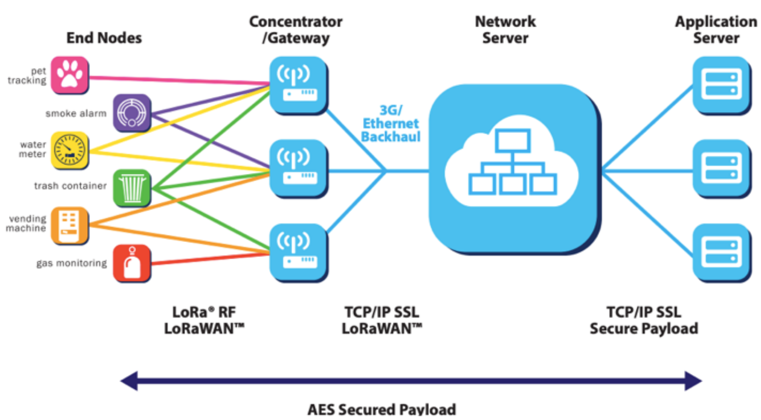


Figure 10: LoRa's architecture
Source LoRa Alliance (2015)

To sum up everything that has been stated so far, the wireless network facilitates the data collection process, and it is subject to specifications that have an impact over the device price, the coverage, and the amount of data that can be transferred. For this study, it is particularly important the influence of the price, availability, and data collection in real-time instead of manually uploading. The amount of data transferred is low, but the range should include a wide area due to the size of an average farm. In this case, the WWNAN network is the best fit to satisfy the user requirements.

To identify the devices and providers currently available in the market, a database specifying technology, type of device, features, and additional functionalities, was created. The information reviewed were found mostly using e-commerce platforms and searching for companies that offer services and devices that involve georeferencing technology. The main keywords used were: “Trackers for livestock”, “Cattle tracking systems”, “GPS for livestock” and “Tracker for Cows”. The inclusion criteria for the devices were: non-invasive technology (the farmer can remove them without using additional tools), and devices designed according to the animal’s characteristics (Cow’s anatomy, for instance). On the contrary, the exclusion criteria include technology software designed only to monitor the cattle, devices to exclusively monitor other variables (not position). The availability in the country and the price of the device were not included as a criterion of inclusion or exclusion due to the main objective of the database: Identify existing technology and characterized it. The flowchart that illustrates the elaboration of the database of devices available in the market is shown in figure 11.

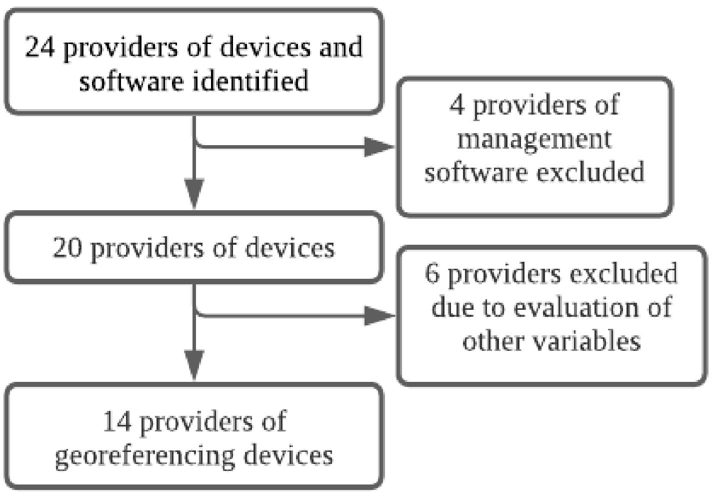
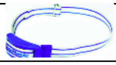


Figure 11. Flowchart of devices data base
Source: Own Authorship

Specifically, a total of 14 devices were found and characterized, that includes Collars and Ear tags. In general, the devices incorporate sensors to supply a complete service, creating a virtual fence, finding illnesses, heat, nutrition indicators, fertility, among others. The collar is the most common device type and incorporates different tracking systems. The ear tag is smaller and lighter than the collar due to the location in the animal’s body. The installation requires a device to pierce an animal’s ear. This is a widespread practice in the sector, which is used for identification purposes. The database with all the devices evaluated can be found in the table 2.

The selection of the best device will depend on the specific characteristics and needs of the farm under study: Its location, the budget, the mobile coverage, the access to electricity, among others. To evaluate these specifications and the ideal device, an AHP was proposed, and will be explained in the section 4.2.2. The following database provides an overview of devices available around the world, 6 of which are available in the country. Specifically, the GSM/GPRS devices require mobile coverage to obtain real-time information on the website or in the mobile app, which can make its implementation more difficult in remote areas of the country. On the contrary, devices with antenna, router and/or gateway, usually LoRa or Sigfox, only require electricity or batteries for its operation and the range includes maximum 50 km.

Table 2. The database of devices considered for the study work and Colombian context.

Provider	Device Type	Technology type				Additional funcitionalities				¿Additional Devices required?	Availability in Colombia	Price (COP)	Photo	Link
			1-5 months	5-12 months	More than 1 year	None	Heat	Health conditions	Behaviour					
NedPad Cow Control	Collar	GPS		x			x	x		No	No	Not available		https://www.nedap-livestockmanagement.com/es/vacuno-de-leche/soluciones/nedap-cowcontrol/
Osmewy Solar Cattle GPS Tracker	Collar	GPS/GSM		x		x				No	Yes	$199,500		https://www.amazon.com/-/es/GT080/dp/B08DRCKBN4/ref=sr_1_2?__mk_es_US=%C3%85M%C3%85%C5%BD%C3%95%C3%91&dchild=1&keywords=cattle+georeferencing+tracker&qid=1609934438&sr=8-2
Winne GPS Tracker	Collar	GPS/GSM	x			x				No	Yes	$185,430		https://www.amazon.com/-/es/dp/B089CXS9JK/ref=sr_1_8?__mk_es_US=%C3%85M%C3%85%C5%BD%C3%95%C3%91&dchild=1&keywords=cattle+georeferencing+tracker&qid=1609934706&sr=8-8
Digit Animal	Collar	GPS		x				x		No	No	$726,000		https://digitanimal.co/
Taurus webs	Collar	GPS/GSM		x		x				No	Yes	$1'200.000 (COP/collar) - Module of software: $3'050.0000	Not available	http://www.tauruswebs.com/wwwtauruswebs/
Yabbi GPS	Collar	GPS/GLONASS			x	x				No	No	Not available		https://www.digitalmatter.com/devices/yabby-gps/
The Oyster2	Collar	GPS/GLONASS			x	x				No	No	Not available		https://www.digitalmatter.com/devices/oyster2/tech-specs/
Cowlar	Collar	GPS/GSM		x				x	x	Yes, router	Yes	$241,500		https://www.cowlar.com/
CowManager	Eartag	GPS		x			x	x	x	Yes, router	Yes	Not available		https://www.cowmanager.com/en-us/solution/system#integration
Sensor Quantified AG	Eartag	GPS		x				x		Yes, Antenna	No	Not available		https://quantifiedag.com/cattle-ear-tags/
Moovement	Eartag	GPS/GSM + LoRa		x		x				Yes, Antenna	Yes	$21000 ($/Tag) $6 USD ($/Tag-Year) $3237500 ($/Antenna)		https://www.moovement.com.au/
Smarter technologies with Orion Data Network	Collar	Radio Frequency Identification and GPS technology		x		x				No	No	Not available		https://smartertechnologies.com/smarter-products/gps-cattle-collar/
Semtech	Collar	GPS + LoRa			x	x				Yes, Gateaway	No	$175,000		https://www.chipsafer.com/about , https://www.semtech.cn/uploads/technology/LoRa/app-briefs/Semtech_Agr_CattleTracking_AppBrief-FINAL.pdf
BouMatic	Collar	GPS + Sensors		x				x	x	No	No	Not available		https://boumatic.com/us_es/productos/boumatic-realtime-activity

Source: Own Authorship

4.2 Phase 2: Methodology design

In this phase, the methodology was designed using Agile methods and the specifics of the process were adapted from the SCRUM cycle with a cycle process that is carried out to deliver a product or a feature for a specific application. In the methodology design, the process of creating the methodology occupied a series of cycles that were called “Sprints”, each Sprint took about 15 days. Every Sprint began with a brainstorming about the methodology, then the team diagrammed it to obtain a workflow of the activities of the methodology and at the end of the Sprint, it was presented to people who work in the livestock sector to receive feedback and inputs for the next Sprint, these people work as the product owner. Finally, the team applied improvements obtained in each cycle and get into the next Sprint restarting with the brainstorming and the complete process, and the resultant methodology is presented in figure 13.

Based on the design cycle briefing explained above, it is important to mention that the principal procedures and concepts used from the SCRUM framework were the following:

- SCRUM Team formation
- SCRUM Product Owner definition
- SCRUM Sprint planning
- SCRUM Sprint review
- SCRUM Sprint retrospective and review

These procedures and concepts are presented in Figure 12 where it is mentioned also how sprints were carried out using the Agile methodologies, specifically SCRUM.

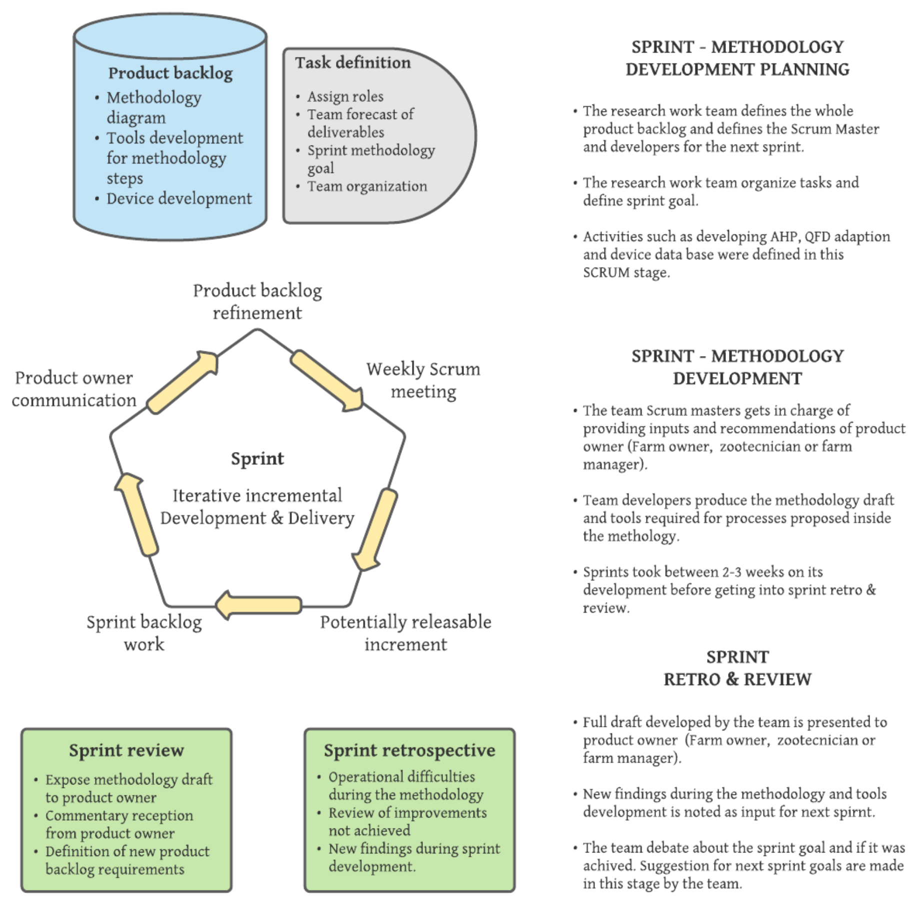


Figure 12: SCRUM application into methodology development
Source: Own Authorship

The steps of the methodology were developed according to the three sprints described on the above figure. Table 3 specify the activities that were carried out during each spring and the results that followed.

Table 3. Activities and results of each sprint

			SPRINT PHASE		
SPRINT #	**DATE** (Estimated)	**DURATION** (Approximately)	**Methodology Development planning**	**Methodology development**	**Retro & Review**
1	December 1st, 2020	15 days	Is needed to submit a first draft of the methodology, including how to select a device, how to know it is the right one, how to learn to use it and how to take advantage of it.	It was presented to product owners a first methodology draft that initially had three steps. It also was proposed the use of tools such as QFD and AHP for device selection.	Product owners as farmers express that it would be better if the testing step was divided in two steps in order to make it easier to understand and carry out.
2	December 16th, 2020	21 days	It is needed to determine criteria to use at QFD and AHP tools. How would it be useful to divide the testing step?	Bibliography review of characteristics of farmers. Meeting with product owners to ask them how each criteria affects them. Proposal of QFD and AHP tools. Proposal to have a first purchase step and a field testing one.	Receive feedback from product owners about the developed tasks during the sprint and identification of potential releasable increment.
3	January 7th, 2021	21 days	Product backlog refinement can be done on QFD and AHP. It is needed to start testing devices.	Corrections on the mentioned tools. Application of the tools on the study case farm. Purchase and testing of the first device in a controlled environment.	First device didn´t work as expected, these aspects should be new inputs for the methodology.
4	February 10th, 2021	30 days	Is needed to test another device. Which is the best way to present data gathered and add value to the farmers?	Purchase and testing of the second device in a controlled environment. Research and proposal of variables for analysis that could be useful and easy to understand for the farmers. Data analysis code draft. Financial limitations for the study case and search of possibilities for data collection.	Present the developed tasks to product owners. Receive feedback about the proposed variables. Idea of creating a minimum device requirements test. Device development option emerges.
5	March 12th, 2021	40 days	Needed issues for device development.	Development of the device, test on a controlled environment.	Present the device to product owners.
6	April 20th, 2021	21 days	It is time to test the device and collect data. Steps at the methodology that do not contain data analysis need to be finished.	On ground testing and data collection. Proposal of a dashboard. *Checklist of minimum requirements* proposal and review of the four steps at the methodology.	Present the dashboard to product owners. Receive feedback from product owners about the methodology.
7	May 20th, 2021	30 days	Final corrections and details need to be completed. Concept proof should be done to validate the methodology.	Details edit at the methodology. Focus groups development to validate the methodology. On ground testing # 2 and # 3 of the device to validate dashboard performance and uses.	Present the methodology to product owners and to study case farm owners.

Source: Own Authorship

Every step of the methodology has a reason and a procedure, this phase also presents the selection of necessary tools and instruments for the development of the methodology proposed. In general, it is explained how the farmer can identify the type of technologies applicable to his necessities through an adaptation of the Quality Function Deployment (QFD), and how a farmer can select the device that better fits his context, using the Analytical Hierarchical Process (AHP). In addition, there is shown how the study case was approached and what type of software will be used for the data analysis and the results presentation in a dashboard.

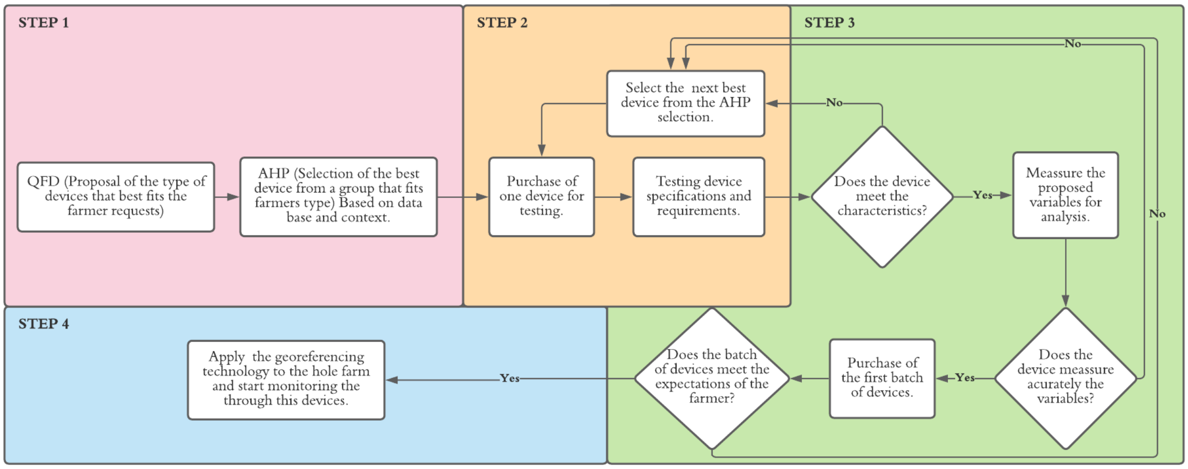


Figure 13: Application of the methodology workflow

Source: Own Authorship

The proposed methodology has the objective of giving a roadmap to the farmer to apply georeferencing technologies for its specific context. As it is shown in Figure 13, the Methodology is composed of 4 steps. In the first step, the farmer understands its necessities and the type of device of the georeferencing technologies that satisfy his requirements. For this step is used an adaptation of the QFD, and then is shown a way to select just one device from a group of alternatives, with the application of an AHP. In the second step, the farmer purchases a single device for testing strengthens the use of the device and learns how to use it. Then, in the third step, it is proposed the measure of specific variables such as displacement and speed that are obtained as results of position and time. Finally, in the fourth Step, it is presented a way to analyze and visualize the information gathered from the georeferencing device and the phase in which the farmer could apply the technologies to the whole farm.

It is important to mention that the process shown at Figure 13 has three steps where it can stop and restart the from the activity of “Purchasing the device for testing”. This occurs because throughout the study case it was identified that the most complicated stage, in addition to data analysis and visualization, was the selection of a device that fits to the criteria to be implemented. The solution is to buy a sample and verify its proper functioning before selecting the one that will be applied to the whole farm. Those loops can prevent the waste of resources and time on devices that will not reach the farmer requirements and guarantees that the final device selected is going to work properly. This process could take some time and that is limitation of the case study.

4.2.1 Engineering tools to select georeferencing technologies (Tools for Step 1 and 2)

Based on the understanding phase, it is necessary to identify the type of devices that best fits the farmer context and as within the available types of options, also it is presented how to select the best one according to previous restrictions and criteria. To fulfill the first statement, an adaptation of the **Quality function deployment (QFD)** was proposed, followed by an **Analytical hierarchical process (AHP),** to accomplish the second one. These two engineering tools are going to be used to select the proper device for the study case based on the environment and farm conditions. Also, these will be a guide of how other farmers can use the same tools to their specific context and necessities.

To identify the farm characteristics and restrictions, it was proposed an adaptation of the quality function deployment (QFD). QFD is used to translate customer requirements (or VOC) into measurable design targets and drive them from the assembly level down through the sub-assembly, component, and production process levels. The QFD's adaptation only uses the main matrix of the function and the customer importance rating. The matrix has standard rates for two types of farmers and includes parameters like network requirements, required functionalities, and available time to manage the devices (the description of each item and the scoring parameters are in Appendix 6). In the customer importance rating, each farmer can rate the items above in terms of their own needs. The results are a weighted sum between the main matrix scores and the customer importance rating. The higher final score for the farmer type identifies the main requirements of the farmer. According to the type, there is a list of recommendations that will help the farmer in the search, looking for some items that will be better for the farmer's needs, this list can be found in the Table 4. The two types of farmers presented represent, in one case, a small cattleman that has less manpower, fewer resources, needs a function limited device, and is planning to implement technologies on a small scale. The other type represents a bigger rancher who plans a big scale implementation, needing a device full of functions, with more resources and manpower.

Table 4: Device's characteristics recommendation.

Type A	Type B
Search for devices that just use GPS, avoid those that require mobile network or GSM.	Prioritize GPS network, GSM uses should be limited.
Discard devices with lots of functions, search for simple devices that allow you to look at your cattle location.	There are functionalities related to a reproductive state, health conditions and nutritional conditions. Look for devices that, in addition to georeferencing, have some of the mentioned functions that best suit your needs.
Prioritize devices that work with solar energy or high durability batteries.	Battery criteria is not a limitation, do not focus a lot on this item.
Prioritize devices with easy platforms for the data display.	Look for devices with comfortable platforms for data display. (Web page or apps)

Source: Own Authorship

The strategy used for the selection of the specific device from a group of devices that matches the farmers context applies the analytic hierarchy process (it will be named AHP). The AHP is a structured technique for taking complex decisions, based on mathematics and psychology. The qualification scale proposed for the peer review inside the development of the AHP is the one presented by SAATY in 2008, and the criteria involved are the technology, the availability in Colombia, the unit cost and the software and data collection system. After selecting the device and entering Step 2, it is proposed a checklist of minimum requirements to evaluate the first device sample, this checklist of minimum requirements is presented in Appendix 10.

4.2.2 Selection of the tools and procedure for data analysis and results presentation (Tools for steps 3 and 4)

The information gathered by the georeferencing device/devices selected and tested in the Steps 1 and 2, is the raw material of the cattle analysis and the base for the presentation of useful information to help the administration of the farm. For the data analysis (Step 3) of the information obtained, there was selected a determined flow of information and procedures. **Python** is selected for data gathering, analysis and information storage, and for the presentation of the information (Step 4) obtained by the device and the data analysis, **Power BI** is selected as the software for this task.

To propose the data analysis for the information gathered by a georeferential device, it was made a test using information of cattle movement that was obtained from Nottingham University and was used with the help of Professor Milena Radenkovic. This information from Nottingham was a relevant input for this research project. During the field-testing stage, mobility restrictions due to covid-19 made it complicated to collect data, and this information became crucial to get the first approach to analyzing georeferencing data and to facilitate the calibration of the tool developed to analyze the data.

This information of Nottingham University contains the one-day data of movement for six cattle. The information obtained through time was the latitude, longitude, date, and time. The data comes in txt format (example presented in Figure 14), and it was obtained from two online links that were given by the professor at Nottingham University (this is public information):

- https://crawdad.org/
- https://www.zotero.org/groups/2614522/crawdad/

The variables that will be used for the analysis are the following:

→ TIME: This variable represents the time in a scale of time that starts in 1900, where every 1 unit, represent 1 day.
→ DATE: This variable represents the date in which the row data was taken from the satellite.
→ LAT: This variable represents the latitude of the position of the cow.
→ LON: This variable represents the longitude of the position of the cow.
→ TIMEOFFIX: Is the official time in the day, in the range of 0:00:00-24:00:00

```
Archivo  Edición  Formato  Ver  Ayuda
TYPE=GPS;TIME=1152012609000;DATE=040706;LAT=52.839488;LON=-1.251200;TIMEOFFIX=103111.879;STATUS=V;SOG=0.0;COG=0.0
TYPE=GPS;TIME=1152012612000;DATE=040706;LAT=52.839488;LON=-1.251200;TIMEOFFIX=103114.879;STATUS=V;SOG=0.0;COG=0.0
TYPE=GPS;TIME=1152012615000;DATE=040706;LAT=52.839488;LON=-1.251200;TIMEOFFIX=103117.878;STATUS=V;SOG=0.0;COG=0.0
```

Figure 14: Data txt format obtained from Nottingham cattle information.
Source: Own Authorship

The Figure 15 shows the information flow and the software selected for every step of the data analysis.

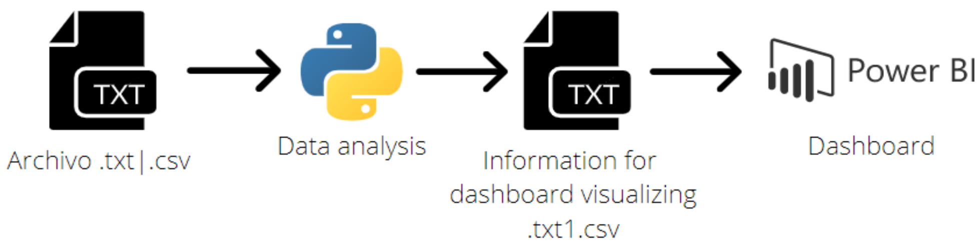


Figure 15: Data analysis flow and engineering tools
Source: Own Authorship

As it was presented in Figure 14, in the first stage all the different documents in .txt/.csv format were organized in a unique folder. In a second stage, those files were read by a Jupyter notebook to obtain secondary variables such as speed and displacement (Look at Table 5 for Nottingham movement indicators) and to obtain the descriptive statistics for these variables. Then in the third stage, the information is exported into a structured table for dashboard creation in Power BI. It is important to mention that there is a difference between direct information and secondary information. The direct information is the one that is detected by the device and stored in the different documents, the secondary information is the one calculated from this direct information. For this study work, the secondary information will be displacement of the cattle and the speed. It is important to mention that the data collection of the devices that are connected through GPS technologies involves a measurement error. According to González Alcaraz, et al. (2010), the parameters that will largely condition the accuracies that we can obtain with the GPS system, and therefore the possible sources of error may be due to the satellites position, the signal propagation medium, or the weather. These errors of measurement specifically came from time (clocks), Ionosphere, Troposphere, Multipath effect, and Errors according to satellite angles.

Table 5: Statistic from Nottingham cattle movement.

Nottingham cattle movement indicators		
	Displacement [km]	**Speed [km/h]**
Number of cattle	6	6
Total measurements	46210	46210
Mean	0.0033	0.0326
Standard deviation	0.0045	0.2122
Min	0.0000	0.0000
Max	0.4720	7.4530

The visualization of the data analysis is going to be shown in two ways, the first visual tool in which the results are shown is a Jupyter notebook for the code, and the Dashboard in Power BI. The results of the Nottingham University data analysis are presented in Appendix 9, and the dashboard designed to observe the data and analysis is presented in Appendix 18.

4.2.3 Results of the methodology design for the implementation of georeferencing technologies in the livestock sector

As it was mentioned before, the proposed methodology was created based on existing methodologies to develop complex activities and the main purpose of this methodology is to guide the farmer into an effective way to implement these technologies. Every step in the methodology has various inside methods that will guide the farmer. Figure 16 expose the activities in each step and gives some guide points for each step proposed on the methodology.

To complement the methodology, a handbook was created to fully describe the methodology in an easy and didactic way. In the handbook, it can be found a deep description of how to deploy the methodology and how to practice each step at it. Besides, the handbook has a stage where it explained in detail way the execution of the methodology in the study case that is presented in section 4.3, showing every implemented step and the tools used. Finally, at the end of the handbook all the tools needed for the correct deployment were linked. The handbook can be found at the Appendix 21.

STEP 1

1. Fill out the **farm characterization format (QFD adapted)** to get a review of the best instrument for the farm context. (Look at Appendix 7)
2. To select the best device of a group of them that fits the charachteristics of the farm, use the **AHP format**. (Look at Appendix 8)

STEP 2

1. With the recommendation obtained in the STEP 1, look at the **table of technologies for and specific context**. (Look at Appendix 7)
2. Buy one device that fits with the recommendations obtained in the table. Take into account the data base included in this study work. (Look at Appendix 5)

STEP 3

1. Test the operation of the selected device and check its operating characteristics with the proposed checklist called (**Checklist of minimum requirements for the operation device**. Look as Appendix 10)
2. If the device fits to the minimum required characteristics, buy a batch of devices at a wholesale price to start testing in a cattle batch.

STEP 4

1. Measure proposed variables on the initial livestock batch of the project in order to corroborate the correct functioning of the georeferencing technologies in the management of the farm. Look at the proposed variable analysis and visulization, and how to produce it on Appendix 9 and 18.

Figure 16: Steps of the methodology proposed.
Source: Own Authorship

4.3 Phase 3: Development of the methodology in the Study Case

In this section, it is shown the proposed methodology applied on the farm of the case study. The purpose is to implement georeferencing artifacts that comes from industry 4.0 technologies and to apply the data analysis proposed, and initially tested with the information of the Nottingham University. Below are the 4 steps of the methodology carried out and applied, except for the full implementation of the devices in the whole farm.

In the central region of Colombia in the department of Meta, there is a farm called *Hacienda La Secreta*, dedicated to cattle raising. The farms have 300 units of cattle, 120 hectares, and an altitude of 520 meters above the sea. This farm was chosen as study case due to the ease of contacting the owners, Mrs. Angelica Lopez.

Mrs. Lopez also gave its opinion and its feedback during the whole study case helping this research project to accomplish its proposed objectives.

4.3.1 Application of QFD adaptation in the farm context

To ease the research for a device that fits the farmers requirements, Mrs. Angelica Lopez, owner of the farm La secreta filled the QFD adapted format and here are the results of this application.

In terms of network requirements, Mrs. Lopez scored 4, which means that there is no mobile or Wi-Fi network on the farm, but it is possible to arrange an installation for the network. For the required functions of the devices, the rate was 5 declaring that it would be better to have a device with georeferencing functions and other options like health or heat information. Finally, for qualifying the available time to manage the device, the study case farm owner gave a score of 2 meaning that two days per year could be destined for managing the devices. The result was a farmer type B, and the given recommendations were the ones mentioned above in the QFD´s adaptation description.

4.3.2 Results application of AHP in the farm context and device Selection

Based on the results of the QFD type of device recommendation, it was used and AHP to select the best device from the ones that fits the farmers context and preferences. The devices that were involve in the selection were the ones that have free information available in the web, including GPS Ear Tag (mOOvement), Winne GPS Tracker, Osmewy Solar Cattle GPS Tracker, Taurus Webs, and Digit Animal (for more detail, look at the spreadsheet of Appendix 8):

The table where the criteria for each device was compared to realize the AHP is the following:

Table 6: Criteria and relationship with devices for selection

Criteria and relationship with technologies			
Technology	**Availability in Colombia**	**Unit cost [$/unit]**	**Software & Data collection**
GPS Ear Tag (mOOvement)	The devices are available in Colombia but there are only sold in quantities over 20 devices.	136.500 COP	Earring that tracks the animal's movement (include software or antenna by paying more for the services)
Winne GPS Tracker	The device is available in Colombia through Amazon.com	190.500 COP	Collar that tracks the animal's movement (Include free software and the is open to cellular connection)
Osmewy Solar Cattle GPS Tracker	The device is available in Colombia through Amazon.com	202.117 COP	Collar that tracks the animal's movement (Include free software and the is open to cellular connection) includes solar charging
Taurus Webs	The device is available in Colombia through http://www.tauruswebs.com/wwwtauruswebs/	1'200.000 COP	Taurus webs is a livestock management software that implements different modules according to farmer's needs. The mapping and GPS module consist in a GPS/GSM collar, with a battery: 3.7v 10.000 mAh Li-ion.
Digit Animal	The device is available in Colombia through direct shipping of the provider	778.715 COP	Collar that tracks the animal's movement (Include free software and the is open to cellular connection)

Source: Own Authorship

The results obtained by the AHP are shown in the next table, it was selected the device "Osmewy Solar Cattle GPS Tracker". As the AHP process indicates, the selected device was the one with the biggest score after weighting the rates by each requirement. The one that have the greater total score is the one that must be selected and if for any reason it is not available, the one with the second highest score.

Table 7: Scores obtained from AHP process.

Technology	**Total score**
Osmewy Solar Cattle GPS Tracker	0.34

Winne GPS Tracker	0.24
GPS Ear Tag (mOOvement)	0.19
Digit Animal	0.15
Taurus Webs	0.08

Source: Own Authorship

According to the results obtained from the QFD and AHP, the devices that best fit the requirements of the study case are the Osmewy and Winnie. The first device was bought through the Amazon platform and was tested according to the specifications. As a result, it was possible to identify that the Osmewy device had an issue with the battery contact, and the mobile app was not working properly. This device had to be returned to the provider. Continuing with the methodology proposed, the second best-rate device (Winnie) was bought, also through amazon, and the results of the requirements test are the following:

Table 8: Specification of best devices selected from AHP for the case study.

Specification	Osmewy	Winnie
Battery efficiency	Not tested	4 weeks of use, 24 hours per day
Price	202.117 COP	190.500 COP
Additional cost	Data traffic plan: 50.000 COP SIM card 2G: 3.000 COP	Data traffic plan: 50.000 COP SIM card 2G: 3.000 COP
Insights	Mobile App: Not functional	Mobile App: Functional, real-time information Web Site: Functional, historical information with 1 day of delay in. XLM

Source: Own Authorship

The Winnie device worked perfectly, and the implementation cost is equivalent to $243.500 COP per device, with a monthly cost of $50.000 COP per device. As a conclusion, the Winnie device is the suggestion to the farmer to implement this technology outside of the academic context.

To proceed with the implementation of the technology into the study case, it was necessary to evaluate the purchase suggestions (Osmewy, Winnie, and Ear Tag Moovement) according to restrictions of applicability for the development of this academic project. These restrictions were: First, it was necessary to involve in the study more than 1 cow to obtain more accurate results, and this was equivalent to acquiring more than 1 device. Second, the shipping time exceeded 1 month, and the provider had limited units. Third and last, there was a limited budget of $1'500.000 COP that was going to be covered by the authors. These restrictions evaluated in each device ranked by the AHP are presented in table 9.

Table 9: Restrictions in applicability of each device Ranked in the AHP in the study case.

	Osmewy	Winnie	Moovement
Cost per unit	This device had an issue with the battery contact, and it had to be returned to the provider	Cost per unit = 195.000 (device) COP + 50.000 (25 GB data plan) COP	Antenna=$3'300.000 COP Device=136.800 COP Maintenance=432.000 COP/year
Total cost (10 cows)		2'935.000 COP	6'072.000 COP
Shipping time		3 weeks	4-6 weeks
Minimum purchase by supplier		1 unit (supplier had limited units)	20 units

As a result, the devices evaluated did not satisfy the academic project's restrictions mentioned above. Therefore, it was necessary to develop a self-made device.

4.3.3 Self-made device's specifications

The device implemented in the study case was self-made and produced with a Raspberry PI and a GPS module configurated through a Python code. Specifically, a Raspberry is a credit-card sized computer that integrates CPU (Central processing unit) and GPU (Graphics processing unit) in the same circuit (Gordon. W, 2019). The Raspberry was connected to a power bank and the operated system was housed in a SD Card of 16 gb. The GPS module is the Neo 6M and provides the following output data: longitude, latitude, and time of its position, with an accuracy in the horizontal position of 2.5 meters and using the NMEA protocol (Standard data format). The device structure is the following:

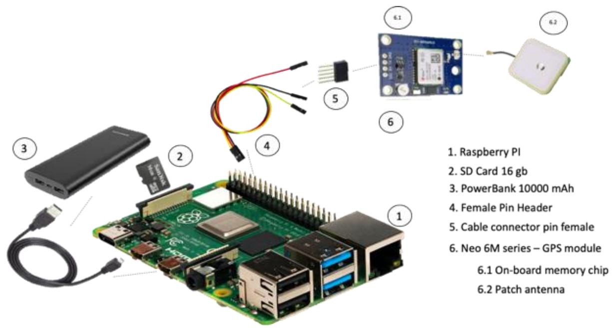


Figure 17 Final device's hardware setup
Source: Own authorship

The raspberry and the GPS module were configurated using terminal (to configurate the data ports) and python (to transcript and print the data in the format: latitude; longitude; time; date). The device receives these information every 30 seconds because of the importance of getting a large amount of data during a short period of time. Due to Covid-19 restrictions and mobility issues across the country, the site testing of the study work will have a testing period of no longer that a 12-hour. This interval of time is also supported by the parameters used in the study made by the Nottingham University about cattle movement, where the information is downloaded every 1 second. Despite this interval is appropriate for testing, the suggestion is to apply a longer interval in a real famer's scenario or in other type of studies where the devices are tested during months. The complete description of the device is in the Appendix 11.

It is important to notice that this device implemented in the study case does not correspond to a purchase suggestion, nor the result of the application of the methodology. It was developed exclusively for academic purposes, specifically for capturing data on the Hacienda La Secreta. The device purchase suggestion corresponds to the one provided by the AHP, as was mentioned in section 4.3.2, according to the context of the farm and the preference and/or limitations of the farmer. The price of the self-made device is lower than devices in the market since the authors previously had one of the main elements, a Raspberry Pi. Table 10 shows the specifications of the device according to the restriction mentioned in the previous section.

Table 10: Restrictions in applicability of the Raspberry Pi.

	Raspberry Pi
Cost per unit	Raspberry=0.0 COP GPS Module=32.000 COP Battery=46.000 COP SD Card=18.000 COP
Total cost (10 cows)	960.000 COP
Assembling time	1 week

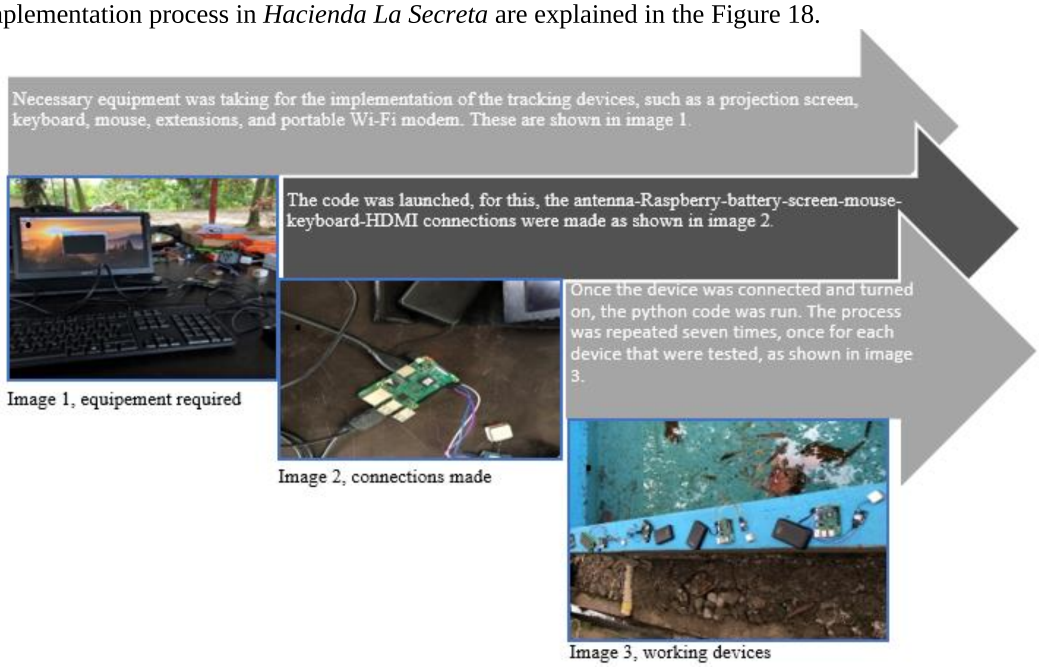
Source: Own Authorship

4.3.4 Implementation of technology in the case study

The self-made device was tested in 2 conditions. The first condition is in a controlled environment (house testing) for properly programming the devices and testing its physical characteristics and connection. The second condition was inside the farm of the study case and another farm near Bogotá for testing the devices in a real environment to collect data. The results of farm tests illustrate the filed binnacle of the study case and are shown in Figure 18.

The first farm test was carried out in a farm close to Bogotá (1 hour by car) one device was tested to verified if the GPS module works outside of the city, and the results were satisfactory, both, the code, and the GPS module of the device, worked perfectly. The second farm test corresponds to the real environment. In this case, 7 devices were tested in the case study farm *Hacienda la secreta* and 4 out of 7 worked perfectly in terms of the code and the GPS module of the device. The last test was carried out in the farm *El Carrizal* located in Facatativá. *El Carrizal* is a dairy farm with 102 animals and 32 hectares. In this last test 2 out of 7 devices worked perfectly in terms of the code and the GPS module of the device.

As it was mentioned the testing process was carried out in two different farms, with completely different conditions (Purpose, location, weather), to evaluate the devices in two environments. The details of the implementation process in *Hacienda La Secreta* are explained in the Figure 18.



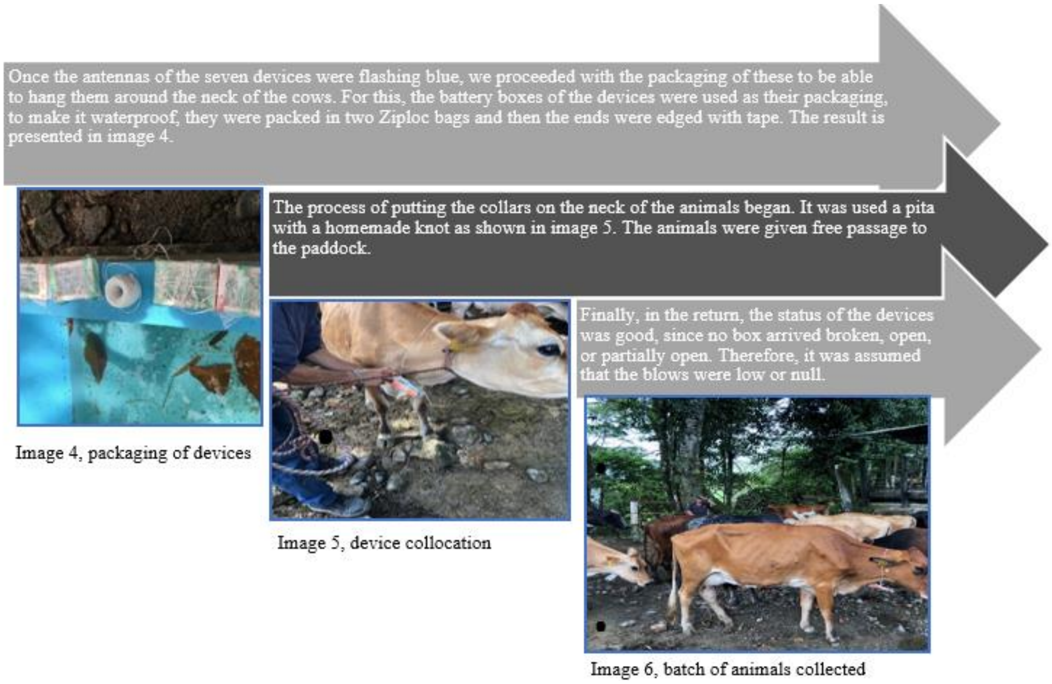


Figure 18: Binnacle field
Source: Own authorship

In the farm *Hacienda La Secreta* the devices were implemented for 11.8 hours. During the testing process it was important to verify different conditions of the device, for instance, the color of the LED light of the GPS module, the shock-resistance, and the water-resistance. In general, it took an average of 7 minutes to flash blue light after running the code, and the packaging of the device was appropriate for brief time. At the return from the paddocks, as it was mentioned before, 4 out of 7 devices had the antenna of the GPS module flashing blue light, which implicated that there were complete geographic data of 4 animals. In *El Carrizal*, the data was collected for 11.54 hours and at the return there were geographic data from 2 out of 7 devices.

Additionally, the Winnie device was implemented during a total of 3 days in El Carrizal with the purpose of getting to evaluate and to compare the results of implementing a device with real-time information. The results obtained from this test is shown is the section 4.4.1. The photographic record of all the testing process can be found in the Appendix 16.

4.4 Phase 4: Evaluation of the methodology applied in the case study.

In this section, it is shown the information collected by the devices and the analysis of that information through Python, the proposed PowerBI dashboard, the farmer's commentary evaluation, and a photographic record of the deployed methodology.

4.4.1 Information collected from devices to be analyzed.

Data analysis made on Python.

As it was mentioned in the method selected for the data analysis, the information gathered with the self-made georeferencing device was managed with Python through a Jupyter Notebook. The analysis covers the manipulation of the variable’s longitude, latitude, and time, to obtain information about displacement, position, and speed, which are the variables that are needed for analysis. There is also proposed a more sophisticated and profound analysis that could be made with a better interface, but that is not in the scope of this case study.

The libraries used for the analysis where: **Pandas**, **Numpy**, **Datetime**, **xlrd**, **Time**, **geopy.distance**, **Geodesic**, **Math** and **Scipy.** These libraries where the ones that facilitate the analysis through Python.

The pseudocode used for the analysis follows the next structure:

```
Run analysis
    Import Libraries
    Import of the georeferencing data collected of different cattle.
    For cattle 1 to Total of cattle
        For iteration 1 to Total Georeferencing Data Gathered
            Calculate displacement between coordinates
            Calculate time between each pair of coordinates
            Calculate speed base on displacement and time
        End for
        Calculate descriptive statistics of the variable displacement
        Calculate descriptive statistics of the variable speed
    End for
Combine all information and data calculated in a single data frame
Export data frame to a CSV document to create Dashboard in Power BI
End code
```

Figure 19: Pseudocode to obtain and analyses data from georeferencing device.
Source: Own authorship

Libraries importation

In the first place, the libraries required for the data analysis where imported. The libraries are the ones mentioned before.

Importation of the georeferencing data collected.

When the libraries are already imported by Python, then the data collected must be charged to start the analysis. The data was imported from a CSV document with the following format of columns and rows:

Table 11: CSV data frame information obtained.

Cattle ID	DATE	REAL TIME	LATITUDE	LONGITUDE
1	12/06/2011	9:05:46 p. m.	52.8394	-1.2512
1	12/06/2011	9:04:16 p. m.	52.8394	-1.2512

Calculation of the variable's displacement and speed

The data obtained from the GPS is essential for the calculations of displacement and speed, these two variables are obtained through the coordinates of the cattle during the time. The displacement between two positions of the cattle in calculated by the "Haversine's Formula" for distance between two points in a sphere. When the distance is already calculated, speed is obtained by the division of the distance in the time between the two coordinates time record (Look at Equation 1). The results were collected as it is shown in the table below.

Equation 1. Speed calculation in every time loop measurement

$$Cattle\ speed = \frac{Distance\ between\ coordinates\ (Haversine's\ Formula)}{30\ second} = \frac{0.012844\ [\mathrm{km}]}{30\ [s]} * \frac{3600\ [s]}{1\ [h]} \cong 1.54\ [\frac{km}{h}]$$

Table 12: Data frame with the secondary variables calculated.

Cattle ID	DATE	REAL TIME	LATITUDE	LONGITUDE	DISPLACEMENT [km]	SPEED [km/h]
1	12/06/2011	9:05:46 p. m.	52.8394	-1.2512	0.012844	1.54128
1	12/06/2011	9:04:19 p. m.	52.8394	-1.2512	0.003052	0.36624

Descriptive statistics of the variables obtained.

For every cattle there was obtained the displacement and the speed as two variables that can be the principle of many indicators to compare the cattle between them and those comparison between indicators are shown in the Dashboard. Based on the information gathered, a simple descriptive statistic was made to understand the variables displacement and speed in the different cattle. These statistics could show the farmer many important characteristics of the cattle of its farm. The statistics of these variable where obtain with the library **Scipy** and gave the following statistics for a cattle data.

Table 13: Descriptive statistics for cattle movement

La Secreta cattle movement indicators		
	Displacement [km]	**Speed [km/h]**
Number of cattle	4	4
Total measurements	4511	4511
Mean	0.0268	1.5107
Standard deviation	0.0836	2.5085
Min	0.0000	0.0000
Max	0.8334	11.6400

	ID	DATE	REAL TIME	LATITUDE	LONGITUDE	DISPLACEMENT [km]	SPEED [km/h]
count	4511.000000	4511.000000	4511.000000	4511.000000	4511.000000	4511.000000	4511.000000
mean	2.545777	44317.950565	0.563010	4.061729	-73.712566	0.026815	1.512707
std	1.126805	0.216798	0.241122	0.032968	0.033064	0.083623	2.508510
min	1.000000	44317.000000	0.000081	4.045778	-73.730509	0.000000	0.000000
25%	2.000000	44318.000000	0.469647	4.046895	-73.729069	0.002150	0.258003
50%	3.000000	44318.000000	0.606296	4.047074	-73.725740	0.004555	0.546631
75%	4.000000	44318.000000	0.741221	4.049119	-73.725093	0.011131	1.335701
max	4.000000	44318.000000	0.999722	4.193039	-73.582613	0.833407	11.640000

Figure 20: Jupyter notebook output for descriptive statistics in the information obtained.
Source: Jupyter notebook software

Exportation of the data for the Dashboard creation.

All the information of the different cattle were gathered in the same data table to export it as a single CSV file and based on that file, create the Dashboard.

Dashboard proposed on PowerBI.

Based on the data analyzed in python to obtain displacement and speed variables, and to organize the amount of data, a management dashboard was created as a proposal of what the farmer could need in terms of information to apply georeferencing technologies in the management of their farm. The dashboard proposed is a prototype of what a device could include in its service for the farmer, and it has all the information that can be obtained from the georeferencing data of the cattle and the farm. The dashboard contains the following Items: Heat map of the cattle position in the paddock, Map of the cattle position in the paddock, Number of cattle tracked, Batch filter, Table of cattle information by cattle ID, Average of variables speed and displacement in a ranking, Weigh filter, and a Filter of every cattle in the farm. There are also Items proposed for future work as Boundaries of the paddocks, Information of rotation of every Cattle, and Cattle batch information. The proposed dashboard for presenting the results of the data analysis is presented in Figure 21.

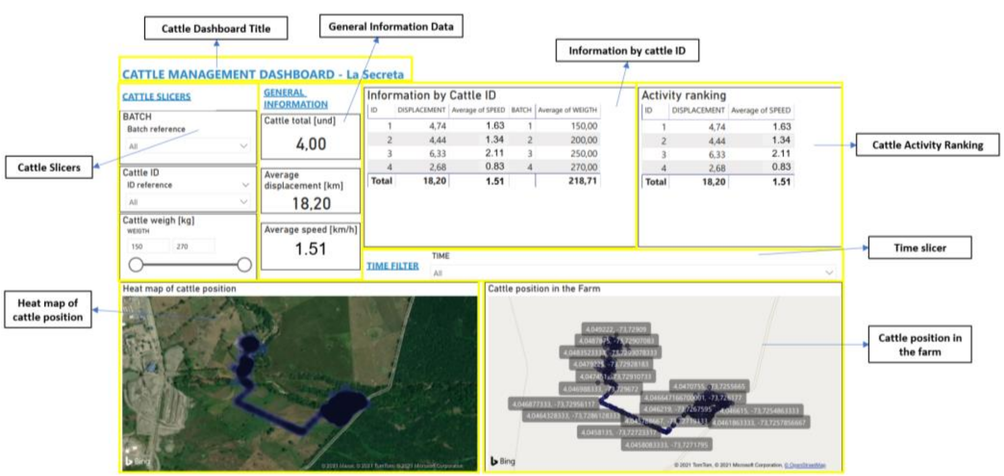


Figure 21: Proposed Dashboard output from PowerBI
Source: Own authorship

This procedure performed can be applied to analyze information collected in a passively way or to analyze online gathered information. As has been mentioned during this document, the proposal is that farmer implement an online device to collect data. An online device was tested to compare the characteristics. The device tested was from the Winnie provider.

The information received by the online device is gathered in the following format:

Table 14: CSV data frame information obtained.

TK935-02155-History route details						
From:2021-07-24 07:00 To：2021-07-27 07:00						
No.	**Position time**	**Lat**	**Lon**	**Speed**	**Direction**	**Track way**
1	**24/07/2021 7:24**	**4.79044**	**-74.3488**	**0**	**282**	**GPS**
2	**24/07/2021 7:39**	**4.79038**	**-74.34898**	**2.18**	**282**	**GPS**
3	**24/07/2021 7:39**	**4.79038**	**-74.34898**	**0**	**282**	**GPS**

The online device gives the following dashboard:

Figure 22 Device provider dashboard output
Source: Winnie Cattle Controller Application

The main differences between the self-made device and the commercial device are presented in the following table:

Table 15: Characteristics comparison between devices tested.

Criteria	Self-Made device	Winnie (online device)
Connectivity	Passive connectivity to analyze data and no-possibility to analyze data in real time to get cattle indicators.	Online connectivity with data availability a day-after to download georeferencing data.
Maintenance	Require maintenance every date that the farmer requires to obtain georeferencing information.	No-maintenance required to obtain georeferencing information, only for battery maintenance.
Flexibility for data use	Full availability for data collection and statistical indicators.	Limited availability for data collection because it is attached to providers specifications and little statistical information provided.
Dashboard information	The self-made device allows to make a more elaborate dashboard that even obtains advanced filters by weight and by batch	The device that collects data online is limited to the dashboard that your supplier has available for use and is limited to filter by batch or weight.
Cost	The cost of this device includes its parts and its start-up.	The cost of this device includes shipping, software created by the provider, and the cost of the data plan for internet connectivity.

4.4.2 Farmer commentary on the deploy methodology.

This section shows the comments made by the owner of *Hacienda La Secreta*, Mrs. Angelica Lopez, regarding the project. The opinions about the methodology and the elaborated tracker device are made by Mrs. Lopez and the whole interview was exposed and recorded in voice notes. For the recording voice notes look at Appendix 20.

After the methodology was applied in the farm, Mrs. Lopez was asked about its opinion and feedback about what she considers are the pros, cons, and results about the implementation of these type of technologies in her farm. The first section of the interview presents the opinion of Mrs. Lopez about situations in which these devices may be useful, the second and third sections of the interview presents the pros and cons that Mrs. Lopez identify in the application of the methodology, and the fourth section of the interview presents the resultant feedback that Mrs. Lopez made about the methodology.

First section – Situations in which this methodology could be useful. For Mrs Lopez, the main use of the methodology to apply georeferencing technologies in her farm is that she can control and supervise the paddock rotation, so she can know if each batch of cattle is in its corresponding paddock at its corresponding time. That could help to the follow up of the rotation plan with the consecutive paddocks. The other main use for her is the security that the georeferencing technology provides. In this case, it is prevented both, theft of livestock as well as cases where the animals get lost, since they enter through areas with dense vegetation or cross the fences. It is also very frequent the cases where the animals must be mobilized trough long roads, many times in these mobilizations the animals are lost, this means significant losses in money. She thinks that only knowing the location of the animals seems possible to save some money in those issues.

Second section – Cons of applying the methodology to the farms. To Mrs. Lopez the issue of water is a big problem for the device since the devices going to be exposed to rain and nature. Also, the issue of the battery that need the workers to be constantly charging the battery. She would prefer if the devices can have a solar panel, so the farmer do not constantly incur battery costs. She made emphasis that her farm has about 300 cows, then it would take too much time for the manager to remove, charge and replace the 300 devices. Also, the issue of the size of the device and the way it is tied to the animal. She considers that it should be as compact and small as possible so that it does not get entangled in some thicket when the cow is grazing.

Third section – Pros of applying the methodology to the farms. In Meta, she thinks that applying the methodology is viable and especially in those farms in Casanare and in Vichada, which have inefficient soils, and the land is cheaper. She said that there, it is possible to find larger farms with large paddocks because farmers cannot afford fences and the animals are free around the whole farm. In this type of livestock farms, the animals are irrigated in large areas so there is a greater possibility that the animals could get lost so the methodology it is very good in that sense because it is easy to know where they are.

She also told that the database, the QFD and the AHP that explain the farmer how to select the devices seems to her very interesting and positive since it will adjust the farm necessities to the methodology. Farms can vary according to their size, but the management of the farms is relatively similar. If you solve the “how to do it” it is more probable that farmers could invest money into these devices and technologies.

Fourth section – Results and feedback about the methodology. Mrs. Lopez made emphasis that the methodology is very useful and that it is the first step that Colombian farmers could take to get into the technological movement in the cattle rising sector, but it also can improve. As an ultimate part of the interview, she said that she finds the cattle dashboard a very interesting tool. The farm owner used to live in big cities. A control panel that shows them information about the animals without having to travel daily to the farm, will give them control and flexibility. Mrs. Lopez also commented that it is important to see how the animal moves through the farm to analyze the behavior of them and its preferences inside the farm. According to her, the devices not only track the behavior of the cattle but also the behavior of the workers, she knows that it is important to trust that the farm worker is doing a good job, but it is very difficult to confirm that daily, these technologies algo monitors the workers and their responsibilities. As a final statement, she said that it is very useful to know about the movements of the animal and ensure that they are in good conditions, because cattle could die, and it could be preventable. She exposes that if she can detect that the animal is moving irregularly, she could have an overview of the cattle health state.

4.4.3 Photographic record of the development methodology proof of concept (i.e., Hacienda La Secreta)

The photographic record of the application of these devices to a herd of cattle and images of the GPS device produced by the authors can be found in the Appendix 16.

5 Results

5.2 Impact evaluation of the deployment methodology in the study case (i.e., Hacienda La Secreta)

To share, discuss and evaluate the proposed methodology, a total of 7 people, including farmers, veterinaries, and zootechnicians, were brought together to develop a focus group. The session was carried out on June 8th, 2021. Specifically, the participants were people who generally have more than 15 years of experience in the sector with knowledge in dual-purpose livestock, breeding, fattening, and raising, and with presence of the Meta, Sucre, Bolívar, and Casanare.

The first discussion was given regarding the level of modernization of the farms in Colombia. The participants had a uniform response, most of the farms in Colombia do not have an adequate level of modernization. It was concluded that technologies are not adopted in Colombian farms because there is no capital for these investments and that there is no technology culture in the people of the sector. In general, the participants come to the idea that the technologies should be applied towards the management of information of the cattle (identification of the animal, days of pregnancy, days of open and/or reproductive indicators), management in the adequate rotation of pastures and increase in forage production.

Regarding the opinion of the methodology applied in the study case, they consider that the application of this technology is complicated due to the low mobile signal coverage in the farms, but it is an obstacle that can be overcome with a device that does not have this restriction. Cost is the greatest impediment since it is considered high, and the assistants suggest that the technology should be implemented in farms that already have been involved in technology, because it does not solve staple activities. Positive opinions were also mentioned, it is a tool that facilitates the management and administration of the farm from anywhere, helping to identify problems of pastures, animals, and administration.

Through the focus group, La Secreta dashboard was presented. The participants considered that the information is well-presented and can give them time and opportunities to improve the labors in the farm. In terms of management, it could improve the control of information, activities within the farm, and it could provide insights of what is happening with cattle and paddocks.

5.3 Economic and operational results from applying the methodology.

Based on the case study, the principal results obtained with the application of the georeferencing devices in the livestock sector can be seen in the economic and operational aspects. The information for the analysis was obtained from the knowledge and experience of the farm owner and workers of the farm *Hacienda la Secreta*. The Figure 22 shows the visual movement detail, which was also the base for the impact analysis. This heat map is included in the dashboard to help the owner and workers to understand how they can visually identify improvements opportunities in their farm. (**Note:** This impact considers the use of commercial devices with full online connection and not with a passive data interface as the prototype developed by the research group team. That prototype was developed in a special situation, but it is not the intention of the authors to propose its own device in the economic and operational analysis)

The impacts identified were the capacity to improve the operations in the farm and a possible investment opportunity that comes with this type of technology. The owner and farmers highlight the impact of the dashboard proposed, specifically, the possibility to track the cattle and to see if it is at the proper paddock of the rotation plan. Additionally, the identification of the preferred areas of the batch of cattle correspond to important indicator of the land's state. As it was mentioned by Mrs. Lopez, in figure 22 it is possible to visually identify those preferred areas for the cattle and what is happening inside the paddock. Mrs. Lopez confirms that it is possible to make some assumption on the track review presented in the dashboard heat map and those assumptions are marked on figure 22. That time that the workers could reduce in their daily activities could be spend better and improve productivity of the farm. In the following paragraphs it is explained the impact calculated based on these observations.

The detail of the calculations for the economic and operational impact were based on information obtained in site from Mrs. Lopez and her farm workers as it was mentioned. Table 16 presents the numerical information used for analysis.

Table 16: Base information for the operational and economic impact

Farm base information and conditions		
Description	**Value**	**Units**
Number of full-time farm workers	4	Workers
Number of extra-workers during year	2	Workers
Full device batch	300	Un
Average price device	$ 250,000.00	COP
Installation: Computer, programs and software required	$ 5,000,000.00	COP
Repairs: 2% of devices every year	$ 1,500,000.00	COP
Maintenance: Batteries, straps and gaskets every year	$ 3,500,000.00	COP
Workers Month Salary	$ 908,526.00	COP
Total initial investment	$ 75,000,000.00	COP
Cost of hiring extra-worker during year	$ 2,725,578.00	COP
Opportunity cost due to time reduction in operational tasks of a daily work shift - calculated monthly	$ 163,534.68	COP
Time reduction of daily tasks through georeferencing technologies	18%	%
Inflation rate per year	3%	%
Projection time on investment	10	Yr
Time of hiring extra workers per year (fumigating, fertilizing pastures and repairs of the farm)	3	Months
Worker's workday	8	hr
Daily time reduction by using georeferencing technologies (Cattle counting, fence check and security)	1.5	hr

In terms of the operational results, it was estimated that using these types of devices, the farm could reduce activities related to knowing the position of the cattle, and that represents a reduction of 18% of the time of a daily work shift by a farm worker, this result comes from the reduction in the daily activities that the georeferencing will replace, those activities are: counting livestock, reviewing broken fences, and movement around the farm that this action means, the owner of the farm affirms that it is approximately 1.5 hours of the 8-hour workday (Look at Equation 2). A time that could be spent in other crucial activities that add value to the livestock business. In conclusion, the operational impact is that the farm could increase available time of its workers and that can reduce the cost of hiring temporary workers (Look at Equation 3), it also provides effective time to improve farm's productivity.

Equation 2. Estimated time reduction

$$\%\,Time\ reduction = \frac{Estimated\ daily\ time\ reduction\ by\ using\ georeferencing\ technologies\ [hr]}{Worker's\ workday\ [hr]} = \frac{1.5}{8} \cong 18\%\ [Daily\ workday]$$

Mrs. Lopez comments that this earned time from full time workers can be invested in the tasks that were carried out by extra workers, this would reduce the operating costs of the farm. Equation 2 shows the reduction of labor costs.

Equation 3. Estimated reduction in labor costs

$$Labor\ cost\ reduction = Number\ of\ extra\ workers\ per\ year\ [workers] * Month\ of\ extra\ workers\ by\ year \left[\frac{Month}{worker}\right] * Worker\ month\ salary \left[\frac{\$}{Month}\right] = 2 * 3 * 908{,}526 = \$\,5{,}451{,}156\ [Year\ cost\ reduction]$$

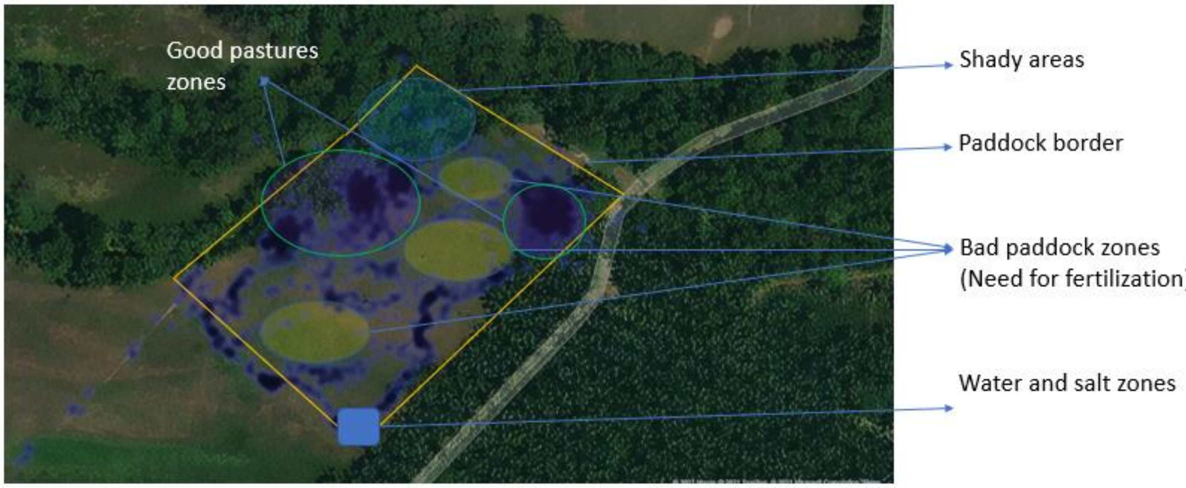


Figure 23: Cattle Movement during study case period in Hacienda la Secreta
Source: Own authorship

Other operation impact was found by monitoring the heat map of cattle movement. Questioning the farmer about what is happening with the areas where livestock travel and the areas which it does not, is the base for visual analysis of cattle georeferencing information shown in the heat map. Areas such as the ones shown in blue in figure 23 are considered good pasture zones and the ones that are not transited by the cattle are the ones with bad pastures. This approach to heat map analysis is validated by the theory that cattle first consume the most nutritious grasses first and then the least nutritious (Motta et al., 2019). The visual analysis approach is also validated by the farm owner that comments that those not transited areas are the ones to consider for fertilizing or to make grass improvements considering the statement that not transited areas could be the less nutritive for the cattle. The heatmap presented on Figure 23 is an own product of this research work but commercial providers of devices for cattle tracking are also including these kinds of maps on its software services for visual analysis.

Mrs. Lopez asks how these georeferencing technologies could be understood as an investment for a farmer. In financial terms, the use of these devices has a return on investment that is obtained by the opportunity cost of workers' time and the reduction of the extra-workers hiring. Considering what it is exposed in Table 16, the investment is projected in a 10-year period considering the costs and incomes that are specific to its implementation. These costs and incomes are resumed in Table 17.

Table 17: Resume of costs and incomes for investment projection

Costs		Incomes	
Item	**Description**	**Item**	**Description**
Installation	Cost of computer, device software training, device installation training, workers training, and time spent to tie up the cows to test. (Providers of commercial devices also gives free client service)	**Farm workers time**	Income provided in time from the opportunity cost due to time reduction in operational tasks such as counting livestock, reviewing broken fences, and movement around the farm that this action means. It is estimated in 18% of a daily work shift - calculated monthly.
Repairs	Cost that estimates that 2% of devices will need to be changed or repaired every year. This is an assumption because of lack of testing or available information.	**Reduction of extra workers for farm task**	Reduction of the hiring extra workers for activities such as fumigation, repairments, fix boundaries with forest, etc. - Estimated in 3 month a year.
Maintenance	Estimated cost of maintenance of batteries, straps, and gaskets every year due to weather and conditions.		

The calculations of economic results were made by a projection of an investment in average commercial devices in ten years, with applicability in farms with a 300 cattle size, the same of *Hacienda la Secreta* and with the assumption of a unit cost of 250.000 COP for every commercial device in the farm. The results obtained were an ROI of 13.6% and an IRR of 5.36%. The projection also includes an estimate of the costs of installation, repairs, and maintenance. In Table 18, it is shown the financial indicators of the investment in the technology for the case study. For detailed information about the economic and operation results, look at Appendix 15.

Table 18: Financial indicators of the case study investment projection

Financial indicators	
Net present value NPV	$ 10,196,916 COP
Rate of return on equity [Annual]	3.00%
Internal rate of return IRR [Annual]	5.36%
Investment	$ 75,000,000.00 COP
Profitability [%]	13.60%
Cost-benefit	$1.086 COP

6 Limitations, conclusions, and recommendations

6.2 Limitations

In the first place, it was the Covid-19 Restrictions. During the whole investigation work, the work team was affected because of the context of the pandemic of the Covid-19. There were restrictions on mobility, travel, access to laboratories or places to develop the GPS device and test it. In the second place, Shipping time limitations. This study case considers buying some devices and adapts them to the investigation work. This strategy was affected because of shipping time and because of that, it was necessary to elaborate a self-made GPS device. The devices that were from China providers, for instance, could reach Colombia in around 8-25 weeks. Also, the methodology presented has a loop in which a farmer would need to buy different samples of devices but in the case of this research project, the time for that activity was also an obstacle because of due dates for the project presentation. In third place, the Measurement errors in GPS Systems. GPS are very practical artifacts, but they are not 100% accurate in their measurements. The GPS antenna used for the case study has 2.5 meters of error in the measure and that could affect the indicators and measures.

6.3 Conclusions and future work

Based on the analysis of the results, impacts, and experience during the execution time of this research project, the following conclusions were obtained:

1. In terms of characterization, most of the georeferencing devices implement technologies like GPS and GLONASS, and frequently the information is transferred through a wireless network such as GSM, GSM/GPRS, Wi-Fi, or LoRa.
2. The implementation of technology in the livestock sector in Colombia is low compared with other countries. In general, there is evidence of inefficient activities on the farm, lack of technification, and, overall, no intention of investing in technology that requires a large budget and understanding.
3. The four steps methodology is accepted by farmers and professional of the sector, they approve that it eases procedure to deploy georeferencing technologies in Colombian farms. People around the sector approves the way it helps characterization of the farm and to evaluate the device that best fits the particularities of each context.
4. The partial implementation of the methodology in the farm "*Hacienda La secreta*" demonstrates the effectiveness of the proposal in a real environment, it could free up the time of about 18% of a day work from a farmworker and that time could be spent on other tasks to improve productivity. The implementation in the case study also theoretically proves to have a positive return on investment if the devices are applied to the whole farm.
5. Experts consider that the application of this methodology can open new paths towards the application of technologies in different branches of livestock production. They consider that the methodology attacks the greatest obstacle that the application of technologies in Colombian farms has, this is the lack of knowledge or the "How to do it". Thus, the methodology is a tool that facilitates the spread of technologies in Colombia, which is a long-term goal of the country sector.

6. The methodology proposed in this research project elucidates the way that companies with expertise in technology and GPS tracking services can open a Colombian market knowing how these devises can applied to its farms.
7. The environmental restrictions of the farm are part of the most important analysis in the methodology proposed, due to the direct impact on the technical specifications of the device. For instance, the implementation of a device with a GSM network on a farm with no mobile connection would be considered a failure.
8. The scope of the applicability of georeferencing in the sector must be opened to include paddock's virtual fences, information about feeding conditions and security options. Also, these technologies should be applied towards the management of information of the cattle, such as identification of the animal, days of pregnancy, and reproductive indicators. The adequate management of the rotation of pastures could result in an increase in forage production.
9. According to the comments made by the focus group participants, the methodology is flexible, and it can be adjusted to specific georeferencing products that wants to specialize in the livestock sector. It could be interesting if technologies can also be linked to information about the animal, such as days of pregnancy, last vaccinations applied, deliveries per year, etc.
10. Georeferencing technologies can impact two fundamental aspects of the livestock sector in Colombia. Those aspects are safety and the reduction of hours of labor in tasks that do not add value.
11. Technologies are not adopted in Colombian farms because there is no capital to make for these investments and there is no technology culture in the sector.
12. Cost is considered the greatest impediment in the application of georeferencing technologies since it is considered high by the people around the livestock sector.

6.4 Recommendations

Based on the experience during the execution time of this research project, the following recommendations were obtained:

- The decision of purchasing a singles device for testing before buying a batch of devices. This came from the certainty that the provider can´t assure the perfect function of the devices in the farm environment.
- The dashboard interface could have better data analysis when the number of cattle rises in number and get into a bigger problem because there is where the management improvement could be seen better, the issue is that this increases the cost of the case study.
- This type of study that depends on a self-made artifact should consider the boundaries that the battery, the mobile signal, and the material resistance produce.

7 Appendix

All the annexes are attached to this study work. The annex index is shown in the following list:

→ *Appendix 1 - Methods for methodology creation*
→ *Appendix 2 - Understanding Colombian farmers*
→ *Appendix 3 - Farmer's survey*
→ *Appendix 4 - About georeferencing technologies*
→ *Appendix 5 - Georeferencing data base*
→ *Appendix 6 – QFD's Adaptation*
→ *Appendix 7 – Focus Group Recording*
→ *Appendix 8 – AHP georeferencing device selection*
→ *Appendix 9 - Nottingham data analysis*
→ *Appendix 10 - Checklist of minimum requirements*
→ *Appendix 11 - Device's specifications*
→ *Appendix 12 - Python code for data analysis in Jupyter*
→ *Appendix 13 - Focus group development and results*
→ *Appendix 14 - Focus group invitation*
→ *Appendix 15 - Economic and operational results*
→ *Appendix 16 - Photographic Records*

→ *Appendix 17 - Dashboard – Carrizal*
→ *Appendix 18 - Dashboard – Nottingham*
→ *Appendix 19 - Dashboard – La Secreta*
→ *Appendix 20 – Voice recording from the farm owner interview.*
→ *Appendix 21 – Handbook: How to implement georeferencing technologies in your farm*
→ *Appendix 22 – Power BI Dashboard documents*

Focus Group assistants

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