THE USE OF DATA-DRIVEN FARMING IN PREVENTING

LOW PATHOGENIC AVIAN INFLUENZA

Author: Carlota Laborda Ruiz
Director: Raquel Moreno Loshuertos

Contents.

Abstract.

Avian Influenza (AI) is a highly contagious and deadly respiratory disease that costs thousands of animal lives per month all over the world. Today's objective is to early detect the presence of the sickness in order to start prevention and treatment measures before the outbreaks spread and massive slaughter is needed. By researching symptoms, risk factors and technology and regulation limitations, the aim of the study is to develop an effective protocol that fulfills this need and saves money and time for the farmers and contributes to maximizing food production, that will be essential to keep up with the incoming overpopulation. Data-driven farming will be the core of the methodology used to interpret and gather big data coming from monitoring various internal and external factors that imply that the disease is present. This discipline will help the farmer into decision-making activities regarding measures for effective prevention that control the sickness. The study is mainly a bibliographic research that bases the results on previous prevention and AI detection tools used in the area symptoms surveillance and real-time data managing. What is innovative is the collective approach that the protocol is implemented in, rather than a tool for individual farmers. The target is the poultry production in France, focusing on risk of diffusion areas and complementing with the cooperation of farmers of neighbor or commercially related farms. The chosen variables to be monitored aim to assure an early detection of infected chicken and useful implementation of prevention measures. The lack of experimental steps supposes a limitation to the study, but its bases are funded on similar cases where the methodology has been proven to save time, money and, more importantly, reduced the production's mortality.

Keywords: Avian Influenza, LPAIV, Data-driven farming, transmission vectors, Big data, outbreak, POCT, symptom surveillance, Precision Livestock Farming.

I. Introduction.

We are facing nowadays the beginning of a major crisis regarding the rise of prices in food, gas, light, and other goods that have limited availability because of wars, global warming and sicknesses. There is a need for new ways of effective production to keep up with the required amount of food that will have to feed the incoming overpopulation that, by 2050, is expected to increase by almost 40%. Putting these facts in a quantitative approach, in order to feed this drastically increasing population, the *UN Food and Agriculture Organization* (FAO, 2009) predicts that approximately 200 million more tons of livestock will be needed to be produced per year.

An important obstacle to this goal is Avian Influenza (AI). AI is a respiratory disease that affects different kinds of bird flocks on which many farms and bigger enterprises base their income. It is a highly contagious disease that spreads fast and reduces the poultry production dramatically, among others, forcing the slaughter of thousands of infected flocks per year. The 2021-2022 season accumulated around 2.500 outbreaks of the sickness (Adlhoch *et al.*, 2022), involving an enormous waste of food that, as noted before, in a few years will not be sustainable.

The virus is categorized in highly pathogenic (HPAIV) and low pathogenic (LPAIV) Avian Influenza. The following study focuses on the poultry production in France. HPAIV's detection is not currently a challenge as poultry tend to quickly show symptoms, including mortality (Alexander and Capua, 2008). For LPAIV, the prevention methods are based on "syndromic surveillance", that is still being developed (Blagodatski, Trutneva, Glazova, Mityaeva, Shevkova, Kegeles, Onyanov, Fede, Maznina, Khavina, S. J. Yeo, *et al.*, 2021). LPAIV of the H7 and H5 subtypes are of major importance, since once introduced into poultry flocks, they may mutate into a highly pathogenic (HPAI) variant causing severe clinical disease with high economic consequences for the poultry industry (Gonzales *et al.*, 2012). What is aimed with this study is to, using Data-driven Farming, find a correct combination of symptoms to survey in order to be able to early detect LPAIV.

Data-driven farming will allow the developing prevention protocol to use collections of large amounts of data, that can come from different sources and will provide information of the flock's health. What is going to be exploited is the data coming from sensors and algorithms that will inform of anomalies in poultry's behavior (Astill *et al.*, 2018). This will guide the farmer in decision making; for example, start more severe detection methods such as biosensors or exhaustive vet revisions.

The difficulties with LPAIV is that in most of the cases there is an asymptomatic development of the sickness, so the symptoms may start when the time of infection surpasses the first week and will not be so aggressive as when HPAIV strikes (Blagodatski, Trutneva, Glazova, Mityaeva, Shevkova, Kegeles, Onyanov, Fede, Maznina, Khavina, S.-J. Yeo, *et al.*, 2021). Antibodies detection could be a start on the search for the virus in the infected animals.

There is a heavy Regulation (EU) 2016/429 ("Animal Health Law") everywhere in Europe regarding investigation of outbreaks and control measures for Avian Influenza. Since it is a highly contagious disease, and there is no treatment nowadays, when a flock is considered infected, even if it is one individual of many, the policy is to cull the entire flock (Brouwer *et al.,* 2019). At affected farm level, contaminated equipment must be destroyed or treated with preventive hygiene to get rid of the virus, such as cleaning and disinfection. At community farms' level, the measures can extend if necessary, understanding neighbor farms or the ones with commercial relations with the infected one.

Therefore, the prevention method that is aimed to be developed in this study is to control the sickness more in a more collective approach; the biggest challenge is the early detection that will protect other farmers once the disease is detected in a neighbor or commercially related farm. The affected farm will have to put up with the strict regulation and lose their poultry production, but the others will have more time to react and start the preventing and detecting methods in order to avoid the possible risks of infection. Disease awareness and cooperation by the farms in the sector is crucial. Overall, the result and purpose of the prevention protocol, that avoids the spread of the disease, will be a considerable reduction in waste of meat and slaughter of poultry flocks and a rise in poultry production. This will also contribute collaterally to the major goal of feeding the incoming overpopulation.

II. Materials and methods.

The study is based in a bibliographic search of information regarding the development and spread of the disease in an infected animal and through its community, the contagion vectors and the symptoms that are usually a target of detection. For this part, different studies and published articles available online were reviewed for comparing which symptoms and conditions in a farm that favor the spread of the disease. The most used tools were Google Scholar and PubMed, as well as OFFLU reports obtained from the WOAH. The search was conducted towards understanding the epidemiology of the disease, surveillance of transmission vectors and risk factors, state of the art in terms of current control and prevention measures, use of Data-driven farming; methodology and its application in the matter, symptoms detection and scope of the issue regarding number of outbreaks and affected areas. By narrowing the research with specific symptoms, migratory species that transmit the sickness and the type of farming (poultry), the approach could be more specific and provide a fast prevention response from the farms when any of the symptoms appear.

The regulation within the French law and territory when a case is detected and the prevention methods and protocols that are adopted nowadays were also taken into account, as well as the detection measures that are used. The use of the official website of the *Ministry of agriculture and Food Safety of France* could give information about the most affected areas and the updated numbers on affected flocks per year. There was a further approach in understanding the role of Data-driven farming in the decision making of the farmers worldwide, to be able to adapt it to the necessities of the target region. This also allows the research to be accountant to each country's response measures to the disease, and to be able to have added value to what is carried out these days. The innovative aspect of the protocol resides in the combination of the different prevention methods that are used today to upgrade their efficiency and reduce the number of slaughtered animals.

In addition to this research, advice from experts in the area, such as epidemiologists that have experience in the target region is essential. It gives a closer and realistic look of the current issue that Avian Influenza represents and could help in developing a protocol that is more suitable to achieve the desired results. It gave a more specific context in the field where the protocol would be installed and also a realistic prediction of is extent. Current detection and prevention measures, as well as the emerging necessities of the farming community regarding the control of the disease were discussed.

Using these tools, the approach can be science based, adaptative and realistic in its law and problematic context and according to the current necessities of the target region. However, after the research, no experimental steps were carried on because of the short time dedicated to the study. They would be crucial in order to confirm that the developed prevention protocol is as efficient and as useful as desired.

III. Research results.

In order to develop an efficient and precise prevention protocol, a previous research was required to understand the dynamics of the virus in an individual, and within its community, to be able to target the correct symptoms and transmission vectors. Afterwards, identifying technology that monitors them and that provides real-time big data will be key to gather the information needed for analysis and posterior decision making. Therefore, with the right combination of symptoms and monitoring measures, the control of the sickness expansion and its detection should be faster and effective. The treatment of the big data, as well as France's regulation and control measures for AI will be also addressed, combined with an insight of the problematic specifically in the country; the current methodology and prevention measures and research that is being carried on.

a. Principal symptoms and transmission vectors to be targeted for Avian Influenza in the poultry production.

Avian influenza virus can affect a wide range of birds, beside poultry; waterfowl and shorebirds can be asymptomatic carriers. Low pathogenic strains can cause common respiratory signs, whether High pathogenic strains can end up causing the death of the affected bird, with a high mortality rate. It is common that a HPAIV infection arises from mutations of some LPAIV strains, the majority of the AI viruses (More *et al.,* 2017)The identified symptoms regarding LPAIV strains, the main target of this study, are sneezing, coughing, sinusitis, ocular and nasal discharge, ova rupture or a decrease in the egg production, which could evolve into infertility. Renal failure and visceral urate deposition can also be seen in poultry.

The incubation period can vary from days to weeks and its transmission is more often by ingestion or inhalation. The most common transmission is through feces and respiratory secretions, that are found in contaminated food and water, or by direct contact, which is more efficient (Gonzales *et al.,* 2012). The AI viruses have a high resistance to low temperatures, so they can even be found in the farm's equipment. What will determine a proper situation for infection will be the strain of the virus, the host species and the environmental conditions such as ventilation, age of the birds or the farm's size and geographical situation.

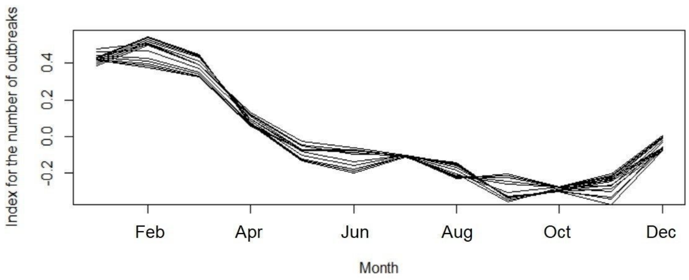

Figure 1: Graph extracted from the WOAH showing the index of the number of outbreaks of HPAI per month. The disease is seasonal, spreading from October to April and peaking in February.

The main transmission vectors that are involved in this aspect are wild birds, being waterfowls (ex: ducks) the natural host and reservoir of AI viruses. Following their migratory routes, direct and indirect (feces) contact between these species and the poultry flock can happen. It is crucial to limit the access of these wild birds to open fields of the farm, and to the water and food supply of the flocks, to stop its transmission to the farm, and the farms nearby or the ones involved in trade or sale agreements.

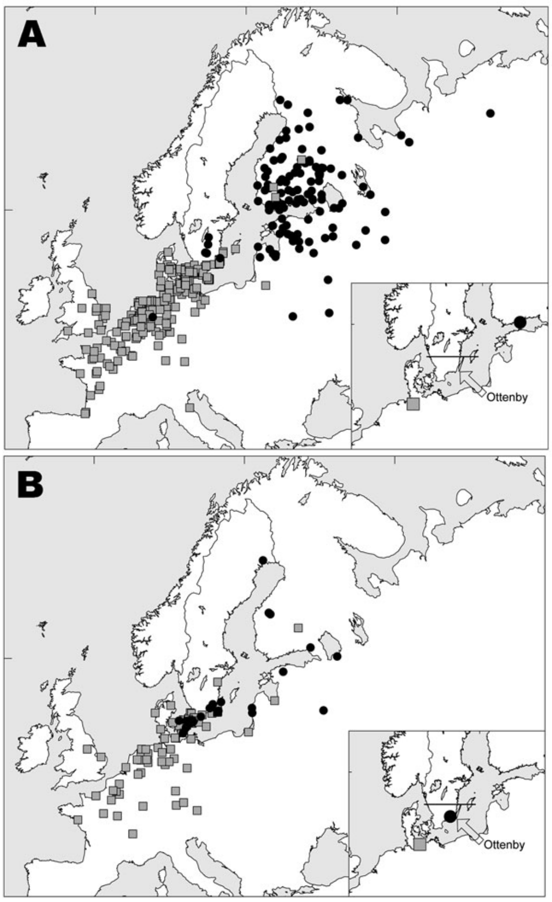

Figure 2: Maps of north-west Europe showing female mallards' recoveries from summer (black dots) to winter (grey squares). The Map A represents the period of time from October to December and the map B represents the period of time from May to September. Symbols on inset maps represent calculated mean positions and the location of Ottenby Bird Observatory (Wallensten *et al.*, 2007).

Regarding the humankind, sporadic cases of transmission have also been reported, being them rare and surrounded by specific conditions. The circulation of a wide range of subtypes of the AI is still a concern to public health. We are also a source of contamination and a reservoir of the virus; caretakers, farm owners, staff, trucks and drivers that deliver food or livestock are also an important transmission vector of the AI.

b. The use of data-driven farming in the poultry production.

The principle of this study is the use of Data-driven farming in the poultry sector to prevent the massive slaughter of the production that provokes each outbreak of Avian Influenza. This discipline is based on the use of advanced analytics and technology to analyze data on various aspects of the farm's functioning. It is commonly used with the objective of helping the farmers in decisions making and improving the farm's overall efficiency and profitability. Some of the data that is gathered includes bird growth, environmental conditions or feed consumption (Wolfert *et al.,* 2017). This can result in the improvement of watering and feeding schedules, and the better understanding of poultry's behavior, giving the farmers the opportunity to identify overcrowding of space issues that can also affect the flock's health.

In our protocol, data-driven farming techniques play a crucial role in monitoring the flock's health state and performance. The symptoms and transmission vectors or risk factors of the sickness, described before, can also be monitored in order to prevent the spread of the virus throughout the farm's production. More importantly, this discipline can help anticipate a major transmission to other farms nearby, the farmers themselves or other flocks that could have been in risk of contagion. Overall, the main aim is to reduce to the maximum the affected poultry production to avoid huge waste of food and loss of money that Avian Influenza is causing to farms nowadays.

When addressing livestock management systems there is usually three separate functions: sensing and monitoring, analysis and decision making and intervention. Precision Livestock Farming (PLF) systems automatize these functions and generate real-time big data, used in decisions making (Astill *et al.,* 2020). The huge amount of data that is obtain will drive data-driven decisions and will require critical data analysis systems for them to be stored, organized and analyzed for consistent results.

i. Gathering big data for AIV detection: principal symptoms that will be monitored.

Regarding AI, smart sensors are currently developed as part of Point-of-care testing (POCT), ISO 22870, they have demonstrated potential for detection of avian influenza virus in poultry. Wearable sensors and biosensors provide real-time transmission of data, giving early and rapid detection for the virus, a very important step to start with decision making and intervention in order to minimize the spread of the disease, principal concern of the farmers. Wearable sensors detect changes in physiology and movement patterns, parameters that vary significantly in presence of infection (Okada *et al.,* 2014). They do not interfere with the normal chicken movement and include accelerometers, low-cost and incorporated in smart devices used in current society. In most of the farms, single animal management on poultry production is not viable since there can be thousands of birds in the same operation. However, PLF technologies target a proportion of the livestock and extrapolate the obtained data to assess the flock's health. There are specific biosensors for avian influenza virus that detect the presence of hemagglutinin protein of H1 or H5 viruses, the last one causing a potentially zoonotic infection (Edwards, 2006).

Vocalization analysis contributes to the detection of sicknesses by associating them with the peak frequency and incidence of the birds' vocalization (Carroll *et al.,* 2014). It is a proved efficient way to detect respiratory infections before clinical signs are shown (Rizwan *et al.,* 2017), which would be the main challenge in LPAIV infections. Remedial interventions can be implemented earlier, and the main goal of this study can be achieved.

Perturbances on the livestock's movement patterns can also be indicator of a threat on the bird's welfare (Silvera *et al.,* 2017). Overhead movement sensors in farms, placed strategically on top of feeding or brewing areas can give a real-time approach on feeding patterns or behavior patterns of the flock. Infected poultry will tend to move or eat less, and that can be monitored with the information that these movement sensors provide. This methodology will be more effective in outdoor farms with low biosecurity, due to the large number of birds that are held in farms with bigger poultry operations.

ii. Big data management: treatment, governance and access.

The data that the previously detailed sensors gather has to be converted and stored for its posterior analysis, the bigger the datasets are, the more important this step is. One option for data-driven farming in poultry production is cloud-based. Its low upfront costs and provides access to analytics and machine learning tools that will analyze the data identifying patterns and optimizing performance. This data management software and the use of sensors reduces the need to entry data manually, by the farmer, rather increases the efficiency of the decision making. In France farming data is regulated by the *General Data Protection Regulation* (GDPR). It sets out rules regarding the collection, use, storage, and protection of personal data of individuals within the European Union (EU). This also includes medical data collected from animals. In addition, the French *Ministry of Agriculture and Food Safety* is responsible for developing policies and regulations related to animal health and welfare, including standards for the collection and management of animal health data. These regulations may require the use of specific data management systems, such as electronic animal health records or veterinary information systems, to ensure the accuracy and confidentiality of animal health data.

c. AI situation in France and current control measures.

The geographical and overall context of the innovation needs to be addressed in order to develop a realistic and helpful tool to solve the problem discussed in this study. *The Ministry of Agriculture and Food Safety of France* provides updated data of the number of outbreaks of AI and latest advances regarding prevention and management of the disease in the poultry production. Since the beginning of 2023, there has been a decrease in the number of outbreaks of AI in France, paired with a decrease in the risk of the virus propagation. The measures were reinforced since 2022 and their follow and surveillance are still crucial to avoid new outbreaks. Preventive culling in either wildlife outbreaks or farming outbreaks and their perimeter is the main measure enforced to limit the spread of the virus. The attributed zones in the perimeter such as protection zones, surveillance zones forbid the movement of poultry inside them. This can be effective although it carries the loss of thousands of birds and the dramatic decrease in production. The ministry also offers a financial compensation to farmers when a case is reported, in exchange of the massive loss of livestock that it entails. Overall, the biosecurity measures in France for AI include the must to wear disinfected clothing and prohibition to any external to the farming areas, especially if we are talking about massive farming. Vehicles that transport any material or resource into the farm must be correctly disinfected in order to avoid possible transmission from either other farms or stakeholders of the livestock farm. Declaring the farming activity is also mandatory. This includes the poultry species, number of animals, traceability data, as well as reporting immediately any case to the veterinary. This is essential to prevent a widespread situation and to decrease the number of affected birds and farms. The *Institut Technique de l'Aviculture* (ITAVI) provides biosecurity guidance for stakeholders in different kind of bird's farming. Either outside or inside farms are contemplated, as well as measures for transportation between stakeholders.

Nowadays these measures are responsible for the decrease in outbreaks commented before and ensures the precise identification of cases and outbreaks. In Mars 25th, the total number of outbreaks in poultry farming in France was 1028. Since August 1st, 2022, there has been around 336 outbreaks of HPAIV, focused on the southwest part of the country. Regarding commercial farming, the number of outbreaks per region are detailed in *Table 1*.

Table 1: Number of outbreaks in commercial farming for poultry from August 1st, 2022, to May 11st 2023 per region in France. These data have been extracted from the Ministère de l'Agriculture et de la Souveraineté Alimenaire of France's official webpage. The numbers represent the position of each region in the original Table, that can be found in the web site.

Number of outbreaks	In commercial farming
Ain (01)	3
Côtes d'Armor (22)	27
Dordogne (24)	8
Eure (27)	1
Eure-et-Loir (28)	1
Finistère (29)	2
Gers (32)	30

Ille-et-Vilaine (35)	3
Indre (36)	1
Indre-et-Loire (37)	1
Landes (40)	7
Loire Atlantique (44)	18
Loiret (45)	3
Maine-et-Loire (49)	44
Manche (50)	1
Mayenne (53)	2
Meuse (55)	1
Morbihan (56)	8
Nord (59)	2
Pas-de-Calais (62)	1
Hautes-Pyrénées (65)	1
Rhône (69)	1
Saône-et-Loire (71)	1
Sarthe (72)	4
Seine Maritime (76)	1
Seine-et-Marne (77)	1
Deux Sèvres (79)	35
Somme (80)	3
Tarn (81)	1
Tarn-et-Garonne (82)	2
Vaucluse (84)	1
Vendée (85)	120
La Réunion (974)	1
Total	336

This information can be really useful to narrow the area of operation for the protocol. In this case, the regions in the country at risk of diffusion of the virus should be the main target, where the considerable number of individual farms are concentrated in a small area. There are two main regions in France where this is the current situation, the rest of the country has zones that have particular risks of contamination with AI, due to possible transmission vectors such as wildlife of migratory species, as shown in *Figure 3*.

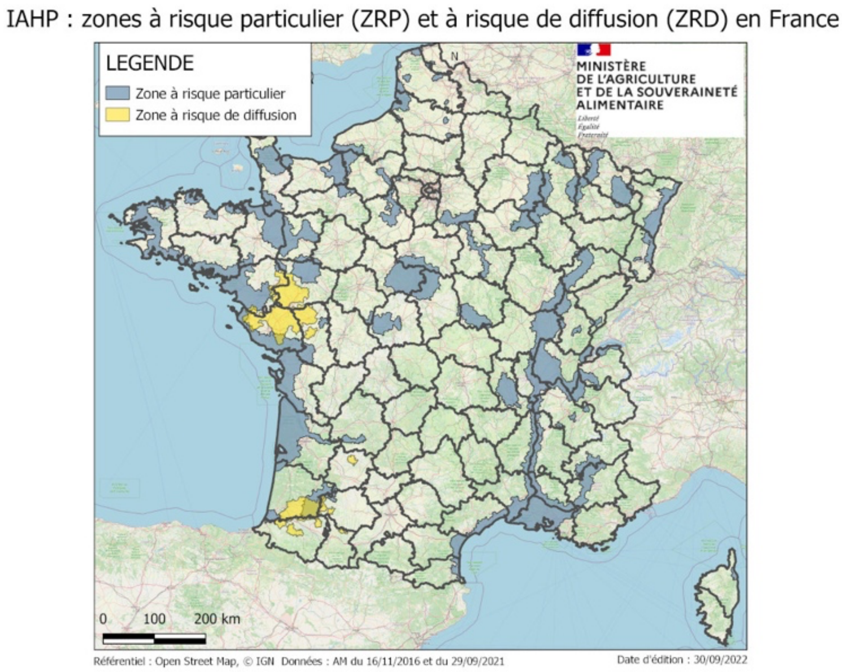

Figure 3: Map of France provided by the Ministère de l'Agriculture et de la Souveraineté Alimenaire of France's official webpage. The zones in risk of AI diffusion are highlighted in yellow, and the zones in particular risk of AI contamination are highlighted in blue.

In order to prevent the widespread of the disease, the Data-driven farming based on protocol that is being developed in this study will be using the cooperation of the data collected by the different farms in the target region. According to the *World Organisation for Animal Health* (WOAH), the *One Health* approach should be an important control measure to implement when speaking of AI. In this study it has been shown the impact that this infectious disease cause in the poultry production, its risk to human health, economy and future population sustainability. The WOAH collaborates with the *Food and Agriculture Organization of the United Nations* (FAO) and with *the World Health Organization* (WHO) to carry on these activities of worldwide cooperation regarding research and development of new vaccines for the disease, divulgation on the different strains of the virus and technical and veterinary advice, available to farmers.

There have been recent advances in this aspect by the *Ministère de l'Agriculture et de la Souveraineté Alimenaire, École Nationale Vétérinaire de Toulouse* (ENVT), *Agence de sécurité sanitaire de l'alimentation, de l'environnement et du travail* (Anses), *Comité interprofessionnel des palmipèdes à foie gras* (CIFOG). Experimentation with vaccines for ducks against H5N1 clade 2.3.4.4b of AI has started since May 2022. The results have shown initial efficacy of the vaccines in protecting and reducing the viral propagation of the AIV. The laboratories that provided the candidate vaccines are Boehringer Ingelheim animal health and Ceva santé animale.

The proposed protocol, that will be detailed in the following, intends to implement the Data-driven farming discipline collectively, targeting rather communities of farmers than individual farms, in order to achieve an effective and early detection of the virus and prevention of its widespread, avoiding the waste of food, the numerous outbreaks and its potential transmission to humans as zoonosis.

d. Our proposed protocol: the use of Data-driven farming to monitor internal and external factors that risk AI infection in a poultry production. Smart decision making to prevent and control the disease.

The data that has been gathered in the previous steps of the research provides a realistic and precise context on where, what and how to design a decision-making protocol with Data-driven farming that will be potentially effective on early detecting and preventing the widespread of AIV.

As discussed, the innovation will target rather a collective group of farms than individual farmers. As a highly deathly and infectious disease AI cannot be fully controlled without taking into consideration the stakeholders or surroundings of the production. The core of the innovation that is proposed in this study is to combine the benefits of Data-driven farming with a wider view of the context of the disease. The WOAH explains that the external factors, such as wildbirds or migratory species, globalization and trade have an important impact into the spread of the disease. Ignoring these factors and only focusing on the close environment of the individual farms will not suppose a decrease in outbreaks and infected livestock.

Therefore, regarding this aspect, the zones in *Figure 3* that are at risk of diffusion will be the main target of the protocol, considering whole farms populations and not individual farmers. This would need funding of the proper authorities on each area, since not all farmers could afford implementing the devices and technology that will be required. There is already a program of compensation for farmers in France when a case is reported, so the regulations could follow the same principle resulting in a financial compensation for those farms willing to implement the proposed protocol. Regarding other transmission vectors such as wildlife, there are some studies predicting the spread of AIVs due to migratory routes of different birds with Kernel density estimations. These should be taken in consideration for periodical veterinary revisions to significant populations of the livestock in each farm, as well as an increased surveillance and measures such as the one regarding trade, imposed by the OIE, where the notification of HPAIV should be separated between “none poultry including wild birds” and “poultry”. Some migratory species that should be under more strict surveillance are ducks (wild waterfowl) or gulls (shorebirds), which are very common nationwide. For the last ones, the OFFLU France’s report in December 2022 explains that the AIV H5N1 (2.3.4.4b) has caused great mortality in gulls in the north and the west of France. These zones of the country match with the target, shown in *Figure 3*. Knowing that AI is a seasonal disease, and the predictions of the migratory routes of these birds, precaution vet test could be arranged in order to start the prevention protocol.

As explained, the organizations cited above work on globalization of control and prevention measures, that also include adequate formation for workers: farmers, drivers… Since we are facing a zoonotic disease, these initiatives will be crucial in preventing transmission from mankind to birds and vice versa. The reports of outbreaks and cases in wildlife, stakeholders, affected farmers or livestock are key to assess the environment of a population of farms, and understand when the risk of infection is most probable in order to start early detection measures that will include vet testing, quarantines and prophylaxis of the disease. The external factors described will be regulated and translated from big data to data-driven farming and clever decision making to prevent livestock culling, loss of income and production and widespread of AI.

Regarding the internal factors that will be addressed, besides health controls for the workers of a farm, the livestock health state will be monitored. As explained before, LPAI is a current challenge in early detection, since HPAI is nowadays very easily detected due to its huge mortality range and notorious symptoms. Therefore, movement patterns and vocalization analysis are the target symptoms for the protocol. It is true that LPAI has symptoms that are not characteristic of the sickness, and the detection could target other kinds of viruses. However, even if at first it does not seem to be a specialized approach, the protocol counts with the monitoring of external factors, that will narrow the diagnosis to most probable detection of AIV infections. That is, again, the core of the innovation, and the importance of the contextualization of the prevention measures. Automated acoustic monitoring of the health of commercial flocks and vocalization analysis can be done with Extreme learning machine (ELM) and support vector machine (SVM) (Steup, Dombrowski and Su, 2019). The modification of vocalization patterns, changes in frequency, pitch, abnormal vocalization or distress calls could be symptoms of disease in poultry. Gurgling noises are symptoms to respiratory diseases, such as AI, that can help with early diagnosis. The main target of these classifiers will be the detection of rales. This study will combine monitoring movement patterns with vocalization disturbances to reach a more complete approach that will lead to posterior vet testing and diagnosis. Movement sensors would be implemented in strategic zones of a farm such as breeding and watering zones. The decrease in appetite and water consumption or a decrease in physical activity in general relates to tiredness and are related to respiratory diseases such as LPAI.

Once the livestock and the internal and external factors, that could risk the infection of AIV in the farm, are monitored, the protocol focuses on Data-driven decision making. Big data analytics and the Internet of Things (IoT) (Astill *et al.,* 2020), that communicates the devices described above, in the poultry industry enable the collection and analysis of large volumes of real-time data, leading to an improved management and, in this case, to implementing rapid detection and start of prevention for AI. The innovation proposed in this study complements intelligent routing protocols; with the monitoring of the factors addressed, with the detection of the AIV using the POCT (Okada *et al.,* 2009) and further intervention of veterinary assistance.

IV. Discussion and conclusion.

Data driven farming is currently a developing discipline that has demonstrated great benefits and advantages in terms of making informed decisions and managing poultry farms effectively. The core of the innovation in the proposed protocol of this study resides in the implementation of this discipline on different farms in the target areas, in order to assure that the collected information from each one is put into a wider context and can be used to prevent the spread of AI. The selected symptoms are thought to detect the disease in an early stage so the massive flock slaughter can be avoided. Besides this, the study is proposed to rather farm communities than to individual farmers, assuring that the collected information is efficiently managed to avoid multiple outbreaks throughout the targeted region.

There are currently different countries where this discipline is put into use. As an example, the Tanzanian small-scale poultry farming community has implemented a mobile-based conversational assistant using the Rasa framework and Android Studio (Shapa, 2021), which is an intelligent decision support system that focuses on daily poultry management activities, enabling farmers to keep records of health management, feed management, flock management, and financial management. The principle of the device is an algorithm that predicts the behavior of the flock and advices the farmer on different matters in the production, but the data initially is not gathered with real time sensors, the farmer needs to ask for answers and in terms of early disease detection it is not as useful. Moreover, the device is suitable for small productions, which is incompatible with the target zones selected in France and the aim of the study.

In France, *Sencrop* is an AgTech startup that developed an application to anticipate disease's outbreaks. It focuses on tracking real-time meteorological conditions to prevent farmers of a risk of crop infection. Providing a personalized monitoring tool, that tracks the crop's growing stage prediction based on governmental bodies and meteorological data, the farmer can use treatment alerts to start preventing the spread of diseases in their production. There is also a history-based prediction according to previous outbreaks that can anticipate the user of risk conditions that could end in a possible infection. As well as the proposed protocol, it requires official organisms to provide local, meteorological in this case, information in order to be precise and effective. For this study the concept is as well used regarding local outbreaks and migratory birds' routes data, that is needed to be reliable and, therefore, implied to be acquired from local organisms that gather this kind of information. Although the principles are similar, extrapolated to livestock (poultry) farming instead of crop farming, the symptoms are detected directly from the flock. This means that there is an internal factor that is being real time monitored. Implemented to monitoring environment and weather conditions, that are the main factors that fund *Sencrop* predictions, it can assure the early detection and prevention of the disease and reliability of the outbreak prediction.

This study aims to propose a protocol that is reliable, efficient and precise to early detect LPAI in poultry productions and prevent the spread of AI outbreaks in risk of diffusion regions of France *(Figure 3)*. The methodology is based on Data-driven farming, well known in the industry and used internationally. This predictive analysis can help farmers anticipate and it relies on specific symptoms of the sickness, that appear before death. By monitoring, analyzing and interpreting real-time big data coming from internal and external factors that imply AI presence, the spread of the disease can be prevented. The symptom's surveillance focuses on changes in movement patterns and livestock vocalization and it is combined with POCT. The transmission vectors of the AIV that are targeted are migratory routes of wild birds and surveillance of real-time number of outbreaks in the area. The cooperation of multiple farms in the target region is crucial to minimize losses in production and to start prevention and treatment measures efficiently. The loss of livestock can be lowered by avoiding massive slaughter from numerous farms and the income and safety of both the flock and the stakeholders, being AI is a zoonotic disease, can be improved. As the need of food is increasing, the proposed protocol can contribute to maximize poultry production and therefore to feed the overpopulation that is predicted to come by 2050.

V. Bibliography.

Adlhoch, C. *et al.* (2022) 'Avian influenza overview June – September 2022', *EFSA Journal*, 20(10). Available at: https://doi.org/10.2903/j.efsa.2022.7597.

Alexander, D.J. and Capua, I. (2008) 'Avian influenza in poultry', *World's Poultry Science Journal*. Available at: https://doi.org/10.1017/S0043933908000184.

Astill, J. *et al.* (2018) 'Detecting and Predicting Emerging Disease in Poultry With the Implementation of New Technologies and Big Data: A Focus on Avian Influenza Virus', *Frontiers in Veterinary Science*, 5. Available at: https://doi.org/10.3389/fvets.2018.00263.

Astill, J. *et al.* (2020) 'Smart poultry management: Smart sensors, big data, and the internet of things', *Computers and Electronics in Agriculture*. Available at: https://doi.org/10.1016/j.compag.2020.105291.

Blagodatski, A., Trutneva, K., Glazova, O., Mityaeva, O., Shevkova, L., Kegeles, E., Onyanov, N., Fede, K., Maznina, A., Khavina, E., Yeo, S.J., *et al.* (2021) 'Avian Influenza in Wild Birds and Poultry: Dissemination Pathways, Monitoring Methods, and Virus Ecology', *Pathogens 2021, Vol. 10, Page 630*, 10(5), p. 630. Available at: https://doi.org/10.3390/PATHOGENS10050630.

Blagodatski, A., Trutneva, K., Glazova, O., Mityaeva, O., Shevkova, L., Kegeles, E., Onyanov, N., Fede, K., Maznina, A., Khavina, E., Yeo, S.-J., *et al.* (2021) 'Avian Influenza in Wild Birds and Poultry: Dissemination Pathways, Monitoring Methods, and Virus Ecology', *Pathogens*, 10(5), p. 630. Available at: https://doi.org/10.3390/pathogens10050630.

Brouwer, A. *et al.* (2019) 'Annual Report on surveillance for avian influenza in poultry and wild birds in Member States of the European Union in 2018', *EFSA Journal*, 17(12). Available at: https://doi.org/10.2903/j.efsa.2019.5945.

Carroll, B.T. *et al.* (2014) 'Detecting symptoms of diseases in poultry through audio signal processing', in *2014 IEEE Global Conference on Signal and Information Processing, GlobalSIP 2014*. Available at: https://doi.org/10.1109/GlobalSIP.2014.7032298.

Edwards, S. (2006) 'OFFLU network on avian influenza.', *Emerging infectious diseases*, 12(8), pp. 1287–8. Available at: https://doi.org/10.3201/eid1708.060380.

Gonzales, J.L. *et al.* (2012) 'Transmission characteristics of low pathogenic avian influenza virus of H7N7 and H5N7 subtypes in layer chickens', *Veterinary Microbiology*, 155(2–4), pp. 207–213. Available at: https://doi.org/10.1016/J.VETMIC.2011.09.016.

More, S. *et al.* (2017) 'Avian influenza', *EFSA Journal*, 15(10). Available at: https://doi.org/10.2903/j.efsa.2017.4991.

Okada, H. *et al.* (2009) 'Wireless sensor system for detection of avian influenza outbreak farms at an early stage', in *Proceedings of IEEE Sensors*. Available at: https://doi.org/10.1109/ICSENS.2009.5398422.

Okada, H. *et al.* (2014) 'Applicability of Wireless Activity Sensor Network to Avian Influenza Monitoring System in Poultry Farms', *Journal of Sensor Technology*, 04(01). Available at: https://doi.org/10.4236/jst.2014.41003.

Rizwan, M. *et al.* (2017) 'Identifying rale sounds in chickens using audio signals for early disease detection in poultry', in *2016 IEEE Global Conference on Signal and Information Processing, GlobalSIP 2016 - Proceedings*. Available at: https://doi.org/10.1109/GlobalSIP.2016.7905802.

Shapa, M. (2021) 'The Nelson Mandela AFrican Institution of Science and Technology NM-AIST Repository https://dspace.mm-aist.ac.tz Mobile-Based Decision Support System for Poultry Farmers: A Case of Tanzania'. Available at: https://doi.org/10.58694/20.500.12479/1635.

Silvera, A.M. *et al.* (2017) 'Lameness assessment with automatic monitoring of activity in commercial broiler flocks', *Poultry Science*, 96(7). Available at: https://doi.org/10.3382/ps/pex023.

Steup, R., Dombrowski, L. and Su, N.M. (2019) 'Feeding the World with Data', in. Available at: https://doi.org/10.1145/3322276.3322382.

Wallensten, A. *et al.* (2007) 'Surveillance of Influenza Virus A in Migratory Waterfowl in Northern Europe - Volume 13, Number 3—March 2007 - Emerging Infectious Diseases journal - CDC', *Emerging Infectious Diseases*, 13(3), pp. 404–411. Available at: https://doi.org/10.3201/EID1303.061130.

Wolfert, S. *et al.* (2017) 'Big Data in Smart Farming – A review', *Agricultural Systems*. Available at: https://doi.org/10.1016/j.agsy.2017.01.023.