Adaptive System to Support Decision-making of Dairy Ecosystem in Boyacá Department

Javier Antonio Ballesteros-Ricaurte[1,3], Angela Carrillo-Ramos[2,3], Carlos Andrés Parra Acevedo[2,3] and Juan Erasmo Gómez Morantes[2,3]

[1]*Escuela de Ingeniería de Sistemas y Computación, Universidad Pedagógica y Tecnológica de Colombia, Tunja, Colombia*
[2]*Depto de Ingeniería de Sistemas, Pontificia Universidad Javeriana, Bogotá, Colombia*
[3]*Doctorado en Ingeniería, Pontificia Universidad Javeriana, Bogotá, Colombia*

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Abstract: Milk ecosystem of Boyacá department is an important economic sector; nevertheless, it presents economic losses due to different problems, particularly, the lack of information to support decision making processes regarding bovine diseases management. It must be emphasized that although there are solutions to this type of problem, most of them only partially fulfill the required functionalities like: disease simulation systems in particular regions, policy management, and notifications for different actors. For these reasons, we propose EiBeLec, an adaptive system to support decision making, where users can visualize information according to their requirements, context, characteristics and information needs, through services. In this position paper, we describe EiBeLec and emphasize on the functionality provided to the government users (*e.g.*, mayor, governor, among others), supporting both decision making and regional infectious disease visualization, in order to provide the authorities, the tools to generate policies and strategies for disease control and eradication.

1 INTRODUCTION

Computer technology provides tools for animal production and reproduction, as well as for control (Bradhurst et al., 2016; Ponge et al., 2016) and eradication of infectious diseases that occur in different livestock regions (Richards et al., 2014). These tools use large data sets to generate reports that serve as support for decision making by people involved. However, the use of such data also requires the development of policies, strategies and approaches to select, analyze and interpret this data appropriately.

An example of this issue can be found in the region of Boyacá, Colombia. The dairy ecosystem of Boyacá generates unstructured data represented in different formats from different sources. For example, (Mojica et al., 2007) reports a case in which data are kept in spreadsheets, while in (Cruz et al., 2014) data is taken from laboratory tests. A quick search was done to find a tool capable of handling this data, but, to the best of our knowledge, there is no dedicated application for the dairy industry, that integrates such data formats, and supports decision making of final users.

In (Weeramanthri et al., 2010) planning is integrated with decision making according to government regulations. However, it does not take into account the use of computer tools. On the other hand, an economic health modeling tool focused on cost savings linked to public health spending priorities is presented in (Sanders et al., 2017); nevertheless, it lacks results in practice, since the tool is under development.

This highlights the need to create EiBeLec; an adaptive information system to support decision making where people involved in dairy ecosystem can visualize information according to their requirements, context, characteristics, and information needs.

This paper focuses on the description of the EiBeLec adaptive system architecture in terms of its components and relationships. EiBeLec takes into account different dairy ecosystem roles. However, for the purposes of this paper, the role description is limited to government roles (mayor, governor, among others), in order to provide tailored services that help in the decision making process regarding regional disease evolution. To achieve this, EiBeLec considers user profiles and its context. For example, government actors should have a holistic view of the

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disease evolution in the whole region, while farmers would only need the information for its vicinity.

This paper is organized as follows: section 2 presents works related to bovine diseases, support systems for decision making and relationship between data and tools used to present information. Section 3 describes the EiBeLec adaptive model, each layer and adaptation to content and display. In section 4, we present a case study emphasizing on the government role. Finally, in section 5, we present the conclusions and some pointers for future work.

2 RELATED WORKS

The analysis of related work is done from three perspectives that involve areas such as bovine epidemiology, adaptation, and use of information and communication technologies (ICT).

Bovine viral diarrhea (BVD) is an endemic disease in many countries; it leads to a variety of health disorders that include mucosal and reproductive problems (Martínez and Riveira, 2008, Recamonde-Mendoza and Corbenilli, 2015). Additionally, there is no complete information on BVD prevalence in farms context (Cowley et al., 2012) generating inconveniences for control and eradication. The resulting impact on economic productivity of cattle has turn BVD into a target for control strategies in a selection of regions including Austria, Scandinavia, Finland, Germany and Switzerland (Tinsley et al., 2012).

BVD control and eradication programs in cattle in the US have involved a collective decision-making process on the best way to mitigate industrial losses. Givens and Newcomer (2015) describe strategies proposed by Livestock Industry that can be implemented to control BVD considering diagnosis for detection of infected fetus.

In (Santman-Berends et al., 2015) a model was developed to predict BVD prevalence and subsequent costs. The stability of the model outputs was evaluated by comparing outputs of different numbers of iterations. The model has an epidemiological component in which a susceptible stochastic (S), infectious (I), recovered (R) or vaccinated (V) model was used to represent the BVD risk of incidence. The output of the epidemiological component is used as input for an economic component that uses information about losses due to infections with BVD, costs of vaccination, participation in BVD voluntary eradication programs, and costs of different testing and elimination of livestock. It is recommended for BVD control scenarios to be implemented not only in the dairy industry but also in the meat industry to maximize the benefit of BVD control.

Table 1 shows works related to BVD and the use of an epidemiological model to assess the disease's contagion and strategies to control and eradication.

Table 1: Related works on infectious diseases.

Criteria	Machado et al., 2015	Cowley et al., 2012	Givens et al., 2015	Santman Berends et al., 2015
Why use epidemiological model?	Prediction	Analysis	Analysis	Prediction
What kind of computer application is it?	Statistical program	Statistical program	None	Spread sheet
The work defines disease control policies	Yes	Yes	Yes	Yes
What are the information sources?	Surveys	Private data	Private data	Private data
Context type that takes into account	None	Flock	Farm	Dairy farm
Who is the application for?	N/A	N/A	Livestock Industry	Dairy farm

A dynamic model to specify socio-economic, cultural, and ecological factors qualitatively is proposed in (Mumba et al., 2017). It enables individuals to identify spatial phenomenon directly on physical maps, and integrate that information into model development. These problems vary considerably in space and context, suggesting that a policy of a single size will not be effective. Therefore, design and implementation of policies must consider local needs in order to generate effective interventions to control diseases within the communities.

Armstrong and Kendall (2010) propose the establishment of knowledge networks as a promising method to support rapid adoption and generation of health information regarding disease behaviour. These networks will be particularly important for implementation of national reform agenda, responsive decision-making and translation of new frameworks or competencies into practice. In addition, it describes how interdisciplinary knowledge networks establish a series of priority areas of health research. Knowledge networks composed of health professionals, decision makers of health services, researchers, legislators and consumers, who have the capacity to provide approaches to build useful evidence at the point of health service. After analysing the article, it can be concluded that information technologies provide a means by which knowledge can be stored and shared by multiple users in different locations.

Due to lack of updated information in livestock census, decisions cannot be made on time and policy planning is obstructed (Hollings et al., 2017). Auto-learning methods have been proposed for estimating livestock due to their potentially higher predictive performance, and their ability to directly incorporate complex interaction effects and noisy data (Robinson et al., 2014; Elith et al., 2006). Advances in computer skills, software and statistical innovation (Guisan and Thuiller, 2005) have made machine learning techniques provide support for decision making in an emergency response situation.

Table 2 presents works related to relevance in decision-making oriented to health issue, in this case, public health (which takes into account human and animal diseases).

Table 2: Projects related to decision making.

Criteria	Mumba et al., 2017	Armstrong and Kendall, 2010	Hollings et al., 2017	Guisan and Thuiller, 2005
There are policies to disease control	✓	✓	✓	✓
Which role makes decisions?	Government	Government	Government	Government
Who has the responsibility to plan strategies?	✓	✓	✓	×
Present information display	×	✓	✓	×

It is important to mention that reviewed projects indicate that there are two main problems: lack of updated information and culture on the part of the roles to report information. Taking into account that these projects focus on relationship that can occur between public policies, and control and eradication of infectious diseases, there are no results that articulate use of computer tools, infectious diseases in cattle and policies of control and eradication; It can also be evidenced, the lack of information about context where infectious diseases are present. It is clear that a system like EiBeLec is needed to fill this gap. EiBeLec is an adaptive system that tests visualization and information services to people involved in dairy ecosystem of Boyacá in order to support them in decision making. This system is explained below.

3 EiBeLec

A phased methodology was followed to define EiBeLec taking into account three models in a generic way: the infectious disease, the dairy ecosystem, and the context of use considering the adaptive model that is explained below.

3.1 Definition of the Adaptative Model

The adaptive model has contextual variables of the disease, the logical architecture of the adaptive system, roles, and services offered by the system. This model takes into account adaptation in terms of content and deployment of information. Adaptation model must consider data sources and information updates. To achieve this, the model includes processes for disease context, dairy ecosystems, and roles.

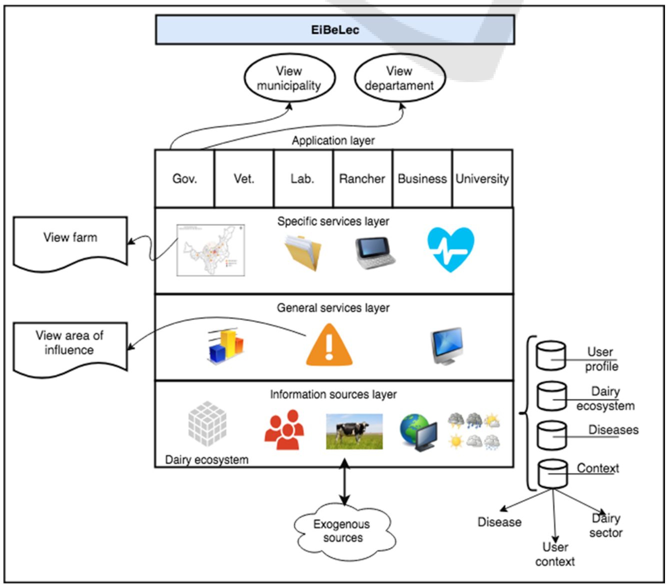

Figure 1: Proposed architecture of the adaptive system.

Figure 1 shows the system architecture that is composed of four layers. The lower layer corresponds to Information sources, where adaptation data and domain models are found. Contextual variables are configured depending on infectious bovine disease that is going to be simulated. In general, there are variables common to diseases such as: temperature, milking practices without good disinfection of equipment, loan of breeders, artificial insemination, high movement of livestock, among others. Some information sources could be: government basic sources (e.g. price regulations, farmer census, topographical data, etc.), user profile repositories, specific government sources (e.g. infection reports, tests, treatment protocols, etc.). These data are represented by means of two models: epidemiological and contextual, which interpret data to provide tailored services. Then, we find two complementary layers: general and specific services, taking into account the adaptation of information presented to better suit the needs of the different user profiles. Finally, there is the application layer to offer the functionalities to the different roles that intervene in dairy ecosystem.

3.1.1 Contextual Models

Context is related to: infectious disease, dairy ecosystems, and role environment (see Figure 2). However, for reasons of space, the latter will not be detailed. Infectious diseases have specific symptoms, which serve to determine what disease is occurring. Variables that are related to symptoms are also related to the context of the region where cattle are located. In livestock farms there are several contextual pieces of information that have to be taken into account like: animals that mix with cattle, climate behavior, geographical area where livestock farms are located.

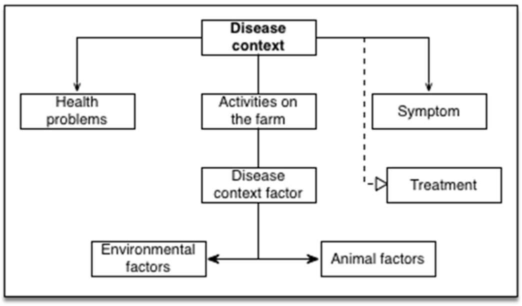

Figure 2: Infectious disease context diagram.

For this paper, we chose the Bovine Viral Diarrhea (BVD) as the disease that is presented in the case study. BVD is a transmissible cattle disease, characterized by fever, diarrhea, anorexia and cough, which corresponds to an epidemic form of disease like postnatal infection of BVD in susceptible herds, also presenting intense diarrhea of short duration, temporary decrease in the milk production and abortions (Martínez and Riveira, 2008). Currently, BVD is considered worldwide as one of the main diseases of economic importance (Machado et al., 2013).

Transmission of BVD virus occurs in four ways: horizontal, vertical, between herds, and within herd. Figure 3 explains how horizontal transmission of BVD virus occurs by: 1) direct contact with infected animals, especially nose-nose, 2) contact through saliva, semen, uterine secretions, placental fluids, and 3) contact with stool, urine, milk and waste.

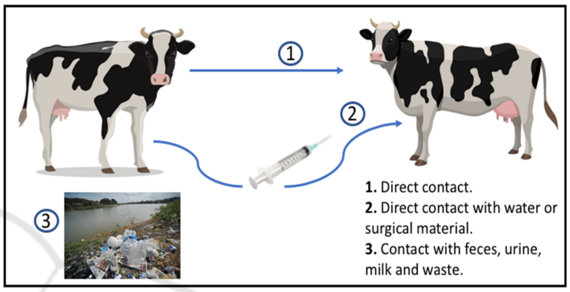

Figure 3: Horizontal transmission of BVD.

Vertical transmission always occurs after embryonic transmission, when a non-immune cow is infected with BVD, a subclinical disease occurs and the virus rapidly crosses the placenta (Martínez and Riveira, 2008). Transmission between herds occurs through acquisition of persistently infected cattle (PI) or females that transport PI fetuses. Other routes of introduction are: use of live vaccines, contaminated semen, cohabitation with cattle, embryo transfer and contact with bovines with acute infection. When an infected animal is introduced to a herd, transmission to susceptible animals occurs rapidly in most herd animals; conversely, when infection is initiated with a bovine with acute infection or by another route that initiates an acute infection, transmission is of short duration and only includes a small percentage of herd before transmission ceases.

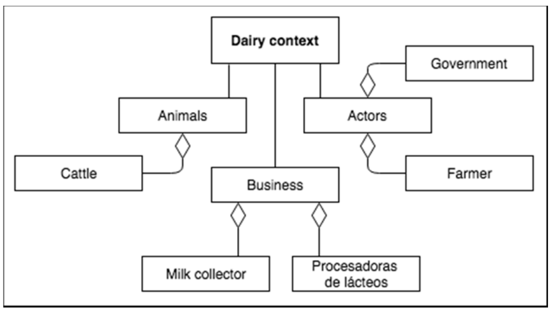

Figure 4: Dairy ecosystem context diagram.

The dairy ecosystem of Boyacá is made up of links such as cattle farms, producers, processors, and milk transporters. Additionally, six roles that intervene in the different processes have been identified; the sum of these links and their characteristics are taken into account in the context description of the dairy ecosystem (see Figure 4).

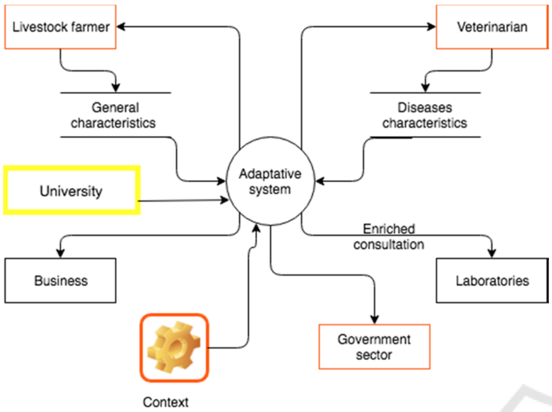

Figure 5: Roles of dairy ecosystem of Boyacá.

Figure 5 shows the people involved in the dairy ecosystem and how they are related both with EiBeLec and with each other. People involved in dairy ecosystem are very important to the system since they fulfill two roles: feeding the system with information about their activities, and acting as final users of the system's decision-support functionality. The present paper focuses on the government role. This role is illustrated in Figure 6 describing the region of influence of government actors (i.e. governors and mayors). The region is divided in departments, municipalities, and towns. It is important to notice that the mayor has influence over the municipalities and their towns, while the governor has influence over the whole region.

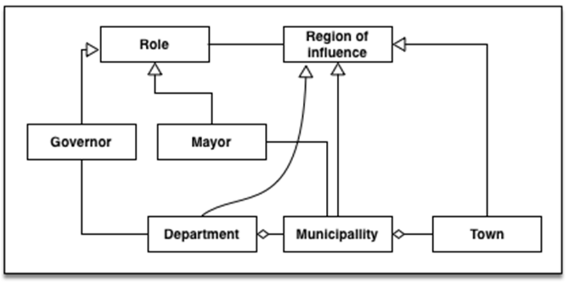

Figure 6: Relationship of government sector.

3.1.2 Services

Services are divided into specific and general, taking into account presentation of information for roles, configured from profiles.

The general services are of public consultation, without the need of a specific profile; nevertheless, specific services are provided according to the user profile. Figure 7 shows an example where a veterinarian uses general services, to verify a disease outbreak, by means of consulting a disease in a municipality and town. In the same way, the Governor can make a specific query to see disease behavior in the department.

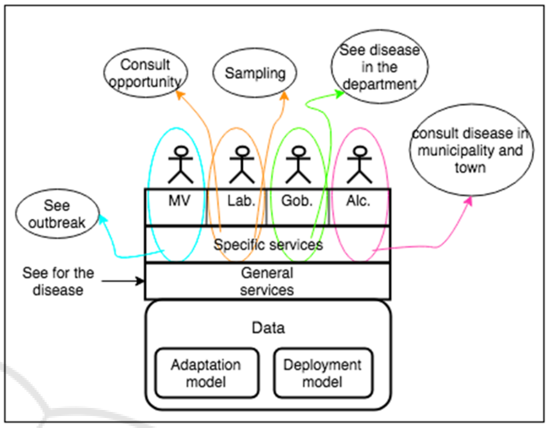

Figure 7: Example of services.

3.2 User Profile of Government Role

Government sector corresponds to a group of actors because it encloses the governor of the region, the mayors of the municipalities that are part of dairy ecosystem in the region, and the municipal and departmental secretaries or bureau of health and agriculture. This actor is the final user of the system, since it requires information, reports, maps and a description of information processed by the system. The functionality of the system is twofold. On the one hand, the government can use it to support decision making processes, in order to create vaccination campaigns, training for farmers in good practices on livestock management, among others. On the other hand, the government can also use the system to detect and prevent possible epidemics, using customized visualizations and alerts based on geo-referenced data.

3.3 EiBeLec System

The proposed adaptive system is composed of different components: information sources, context data, models (epidemiological, social and adaptive), services and actors, each of them has subdivisions and activities that complement the system. In Figure 1 you can see the structure and relationships between components. Next, a diagram of the adaptive model is described (see Figure 8).

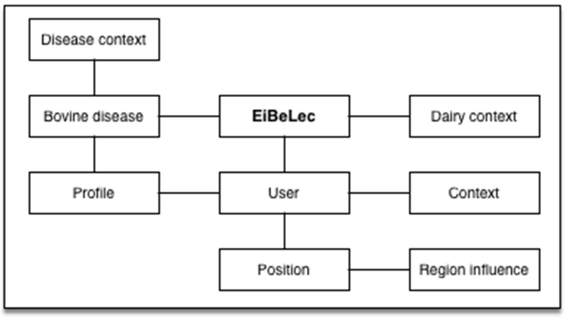

Figure 8: Adaptive model diagram.

Information sources supply the system with data and relationships through different artifacts; It is divided into actors, exogenous sources and the context. Context attributes must be considered because each one obtains information from different scenarios, for example, spatial-temporal that helps to obtain information about physical geography of the region, weather patterns, among others. The adaptive system incorporates models that are directly related to sources of information; they are responsible for processing data, taking into account requirements of the system, enabling stakeholders to access different queries through general and specialized services so that they can make decisions, from the role they fulfill.

4 CASE OF STUDY: EiBeLec FOR GOVERNMENT

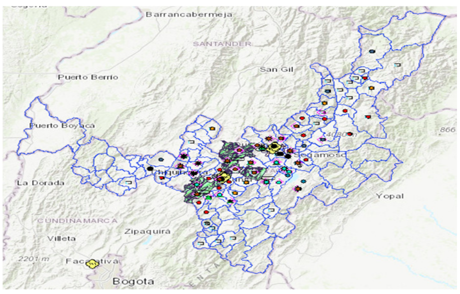

Figure 9: Visualization of virus in towns.

Suppose that, in one of the dairy municipalities of Boyacá, there is a threat due to BVD outbreaks found in some of their towns. In response, the EiBeLec system should provide government actors with a visualization similar to the map shown in Figure 9. Cattle farms are found in different geographical areas, they are close to rivers, lagoons, reservoirs of water, they have different numbers of cattle in the paddocks and might also have horses, goats, among others.

Several situations arise. Disease can spread because farmers have no information about whether their livestock are infected and consequently, they could sell infected livestock in local markets. Also, they might use the same places to feed the livestock. They might as well take cattle to the same paddocks.

Even in the areas without virus alerts, farms might be connected to infected cattle by one of the many links like water reservoirs or milk transportation routes that puts them at risk of contamination.

Farmers have unstructured information about disease, causes and symptoms, economic losses caused by disease in milk production, animal reproduction, and purchase and sale of livestock; no sanitary safety standards apply; and there is little communication between farmers and government sector. This results in a lack of updated information in government officials for decision making, strategy planning, and generation of policies of control and eradication of this type of infectious diseases. Government has different strategies to bring information to farmers, but they have not been effective (Ruiz, et al., 2012).

For these cases, three services are presented to the government sector. The first service is to display maps. Bovine infectious diseases occur in different regions and propagation occurs using contextual variables. This service presents information to government sector using heat maps, taking into account that the governor can see on the map how the disease is distributed in the department, if there are reservoirs of water near the focus of the disease, which municipalities are affected, and which are close to the disease. The second service consists of notifying campaigns. Farmers do not have enough information about control and eradication of bovine infectious diseases. Authorities already organize campaigns in different municipalities, but because of the lack of interest or communication, farmers do not take advantage of these campaigns. The early alert service will notify government officials about BVD outbreaks in their respective region of influence so that they can act accordingly.

It also provides information about diffusion campaigns aimed at farmers. The third service corresponds to the generation of statistics. Decision making is based on data that were processed. However, the dairy sector does not have information systems to capture, store, process and present reports. The service of generating statistics provides information to the authorities so that they can generate policies for control and eradication of infectious diseases like strategies to promote good livestock practices.

To explain the use of services presented to the government sector, two scenarios are described that involve daily activities on livestock farms for decision making by government sector.

Scenario 1: the governor wants to know if there is an infectious disease that threatens public health; If so, where is it happening and what is the behavior of the disease considering: (1) how long ago it started, (2) what can be its transmission estimation in following days, (3) what aquifer systems are in the area, and (4) what are the possible areas and causes where the disease has started. To visualize it, one must have information reported by different people involved in the dairy ecosystem, which informs if there are symptoms of diseases (see Table 3) using a checklist, without the need to report the name of the farm or its location.

Table 3: Check list of variables with disease.

Disease / Variables	S	T	V	X	Y	Z
BVD	✓	✓	✓	✓	✓	✓
Leukosis	×	✓	✓	×	×	✓
Brucellosis	✓	✓	×	×	×	✓
Fasciola	✓	✓	×	×	×	✓

The list of variables that are related to the diseases are: **S**: Abortions. **T**: Reuse of needles. **V**: Artificial insemination. **X**: Use of non-certified semen. **Y**: Mobilization of animals. **Z**: Improper handling of farmyard.

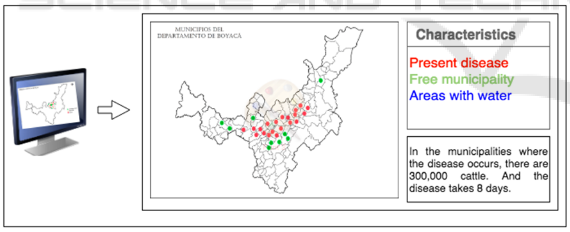

Figure 10: Visualization for the Governor.

In this case, the Governor query the system, clicking on the map (see Figure 10) and a heat map is displayed, showing disease behaviour, zooming in and viewing by regions.

Scenario 2: Vaccination campaigns, training and data related to milk purchase prices are strategies that serve to prevent, control and eradicate infectious diseases. However, this information reaches a very small group of farmers and there is no way to control who is notified. In addition, messages do not reach all farmers. Government sector has information to generate campaigns to control and eradicate bovine infectious diseases. Nevertheless, farmers do not have access to information and communication with government sector is not the most appropriate, since one of the drawbacks is the lack of tools that allow contacting farmers. Figure 11 shows the service of message notification that government sector might use to deliver information to farmers, to notify them about different campaigns.

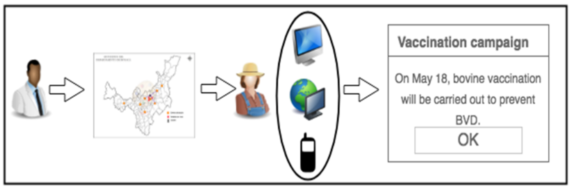

Figure 11: Display notification service.

5 CONCLUSIONS

This paper presents a bibliographic review of projects related to bovine diseases, decision making and people that intervene in dairy ecosystem. Decision making by actors is a very important aspect in processes of dairy sector. There must be a clear, organized information and visualization of results and arguments so that people involved can make better decisions. However, to the best of our knowledge, the systems that have been reviewed do not integrate these services; therefore, we propose the construction of EiBeLec, an adaptive system to support decision-making, was proposed.

As a future work, the platform will be implemented with the services proposed for the roles of farmer and government. An example of service is a simulation of an infectious disease spread in the Boyacá department, taking into account the study of automatic learning algorithms, performing tests to determine which is the algorithm that presents the best results with data of selected infectious diseases. Furthermore, we propose an analysis of algorithms (such as Logistic Regression (Pajares et al., 2010; Chen et al., 2017; Richards et al., 2014), artificial neural networks (Dwivedi, 2016), support vector machines (Truong, Anh, Minh and Le, 2017)) for processing of information, classification of symptoms by means of different variables and the occurrence in different livestock farms, data reported by actors. This analysis will allow the selection of the most appropriate algorithm to be used in EiBeLec.

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