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# Intelligent Decision Support Systems for Industry

**Cuauhtémoc Sánchez-Ramírez (ed.)**

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# Table of Contents

Page

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# Conceptual Design of the Vinasse-Based Livestock Feed Supply Chain

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**Abstract.** This article presents a conceptual model of the livestock feed supply chain that used the vinasses generated by the ethanol industry. To define this new supply chain, we designed a causal loop diagram, which is a tool of the systems dynamic's methodology. The causal loop diagram identified the key variables of livestock feed supply chain, as well as the main interactions between the variables.

**Keywords:** Vinasses, system dynamics, supply chain, conceptual design.

## 1 Introduction

The sugar industry is one of the most important industries worldwide, and it usually applies the principles of circular economy and waste reduction [1]. That is, the various types of waste generated during sugar production are often used to create new products, such as biofuels and biochemicals. According to the Organization for Economic Co-operation and Development (OECD) and the US Food Agriculture Organization (FAO) [2], trends in sugar production indicate that by 2023 sugarcane will remain the dominant sugar crop (about 86%), while only a little amount of global sugar production will come from sugar beet.

According to [3], the commercial fate of ethanol and molasses from the sugar industry is uncertain due to the latest COVID-19 (SARS-CoV-2) pandemic. In Mexico, higher sugar prices due to uncertainty in the market can have a positive impact on the price of sugarcane, which in turn can benefit local farmers but also cause instability economic.

As one of the many byproducts of sugar production, molasses plays a key role in ethanol production and is commonly used to develop animal feed [4].

According to [5], sugarcane molasses is an important source of energy, since it contains components such as sucralose, glucose, fructose, and lactic acid, among others.

The production of ethanol from sugarcane molasses generates vinasse, a liquid residue rich in organic materials and minerals that can be used for fertirrigation.

However, since untreated vinasse can harm crops significantly [6], the scientific and industrial communities have found other applications for vinasse, including energy generation, soil fertilization [8], and livestock feed (LF) production. Unfortunately, the viability of using vinasse to produce animal feed is not sufficiently explored. Hence, in this research, we propose a conceptual model to analyze the potential of sugarcane vinasse as the raw material for the LF supply chain.

The remainder of this paper is structured as follows: section 2 discusses the state of the art on the multiple applications of vinasse, including energy generation and soil fertilization, among others. Section 3 introduces our research methodology, and Section 4 details how we followed said method. Finally, section 5 discusses the research conclusions and our suggestions for future work.

## 2 Background

This section discusses the most common industrial applications of sugarcane vinasse.

### 2.1 Vinasse for Energy Production

The anaerobic digestion of vinasse generates considerable amounts of biogas, which can be used to produce electricity. In [9], authors compared the potential of vinasse biogas to that of oil power plants in terms of energy generation, costs, and greenhouse gas (GHG) emissions in Brazil. In the end, the authors found that vinasse could be a viable alternative to generate electricity in the country.

Also, in [10], the authors performed an economic analysis of vinasse biogas for electricity generation in Sao Paulo.

The analysis calculated the amount of sugarcane and volume of vinasse produced in the region. The study concluded that in Sao Paolo biogas from vinasse could help generate a total of 659 GWh/year of electric power, to be supplied to 295,702 inhabitants and covering 0.45% of the state’s energy demands.

Finally, according to [11], global vinasse production is estimated to be of 22.4 gigaliters, which have the potential to produce 407.68 gigaliters of biogas. In this sense, vinasse is a potential source of renewable energy.

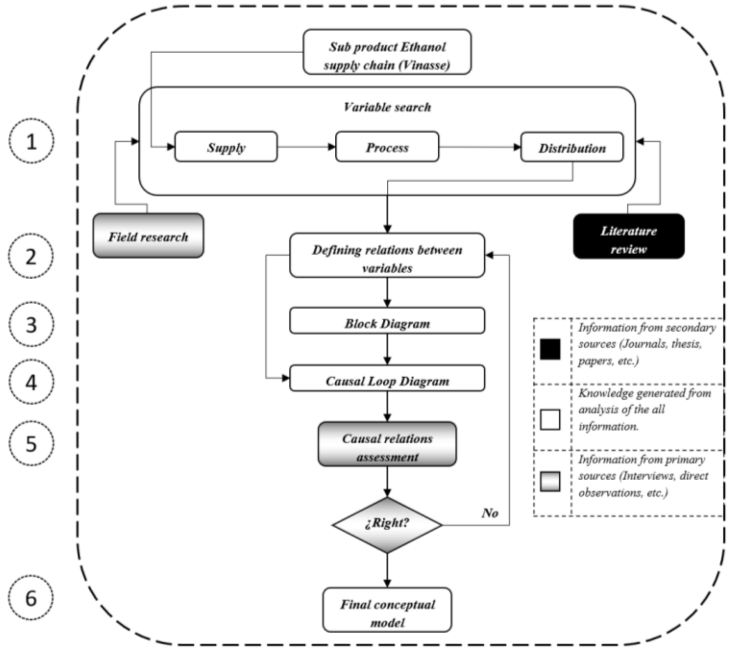


**Fig. 1.** A conceptual model of the vinasse based LF supply chain.

## 2.2 Vinasse as Soil Fertilizer

Sugarcane vinasse is typically used as the raw material of organic fertilizer. In this sense, vinasse-based fertilizers significantly reduce the negative impact that is caused by releasing excessive amounts of vinasse into the environment.

According to [12], the physicochemical and morphological properties of pectin and chitosan, when combined with sugarcane vinasse, have great potential for soil fertilization. Moreover, a study conducted in [13] combined high methoxyl pectin gel with sugarcane vinasse to produce a slow-release soil fertilizer.

Vinasse acted as the biopolymer solvent, providing greater stability to the pectin gel, and as a source of nitrogen (N), potassium (K), calcium (Ca), and magnesium (Mg). Finally, a study in [14] revealed that vinasse combined simultaneously with mineral N fertilizers increases N2O emissions 2.9-fold, if compared to N-fertilizers alone. Therefore, the authors suggested not combing both inputs, but rather applying vinasse before or after mineral N fertilization.

## 2.3 Vinasse for Animal Feed Production

Food waste and crop residues are commonly reused as LF. In this practice, animals act as natural bioprocessors capable of converting food residues that humans cannot eat into human edible food, such as meat, eggs, and milk [15]. The use of food waste and agro-residues as sources of animal feed often requires comprehensive analyses in terms of food safety, natural resource conservation, and climate change.

A study conducted by [16] examined whether land could be shared between food production and biofuel production. The study pointed out at sugarcane as an example of both a food crop and a biofuel crop. On the one hand, sugarcane is used for ethanol production (biofuel); on the other hand, it can produce biomass yeast, a single-cell protein used as animal feed additive. In the end, the multiple applications of sugarcane and its byproducts has an impact on the annual global yield of this crop.

Finally, researchers in [17] discussed the feasibility of replacing edible feed grains with human-inedible biomass in animal diets as a strategy to reduce food-feed competition and mitigate the environmental impact of livestock. From this discussion on state-of-the-art vinasse applications, we conclude that research on the use of vinasse for animal feed is scarce, if compared to the number of initiatives exploring vinasse potential for energy production and soil fertilization.

## 3 Methodology

Figure 1 depicts the methodology followed to develop the conceptual model of the vinasse based LF supply chain. The methodology comprises six main steps:

1. Identifying the model variables,
2. defining the relationships between these variables,
3. building a block diagram,
4. developing a causal diagram,
5. analyzing the causal relationships resulting from the diagram,
6. developing the final conceptual model.

All the steps are explained bellow Search for model variables. We performed a systematic review of the literature using the following keywords: vinasse, supply chain, and ethanol production.

1. Define relationships between variables. Primary relationships between variables were defined as follows: A→B.
2. Build block diagram. The block diagram was built as a graphical representation of the primary relationships identified between variables.
3. Develop causal diagram. We built a causal diagram to graphically visualize complex relationships between latent variables. The diagram also helped us find whether a given variable (the cause) had an either positive or negative impact on another variable (the effect). Causal diagrams also depict reinforcing and/or balancing feedback loops.
4. Test causal relationships. We analyzed whether the identified causal relationships, impacts, and interrelated variables were representative of the system being studied – i.e., the vinasse-based LF supply chain. Once the causal

**Table 1.** Variables involved in the vinasse based LF supply chain.

| Variable | Descriptor | Reference |
|---|---|---|
| Molasses inventory (from supplier) | Amount of molasses that a sugar mill or refinery can supply to an ethanol production factory. | 4, 18 |
| Molasses procurement | The process through which an ethanol production factory procures molasses from a supplier (i.e. sugar mill or refinery). | 4,7 |
| In-factory molasses inventory | Amount of molasses (Ton) stored within the factory and necessary for ethanol production. | 4,18 |
| Master production schedule | Production program predefined by the company according to the number of customer orders received. | 18 |
| Ethanol production capacity | Amount of ethanol produced on a daily basis. | 19 |
| Ethanol production | Process of converting molasses to alcohol through distillation. | 18,19 |
| Vinasse | Residue or byproduct generated during molasses distillation. | 1,5-17 |
| Pollution | Emissions to water (local rivers or lakes) in case vinasse is not treated or contained within factory facilities. | 8,9,10 |
| Vinasse inventory | Amount of vinasse (Ton) stored and necessary for LF production. | 4 |
| LF production capacity | Amount of vinasse processed on a daily basis. | 4 |
| Production costs | Costs incurred by the factory from manufacturing LF, including steam power, electric power, and workforce, among others . | 18, 19 |
| LF production | The production process of LF. | 10, 12 |
| Finished product 5nventtory | Amount of LF ready to meet the demand. | |
| Waste management | Amount of vinasse daily processed to obtain LF. | 13,14 |
| Finished product demand | Amount of LF consumed by final consumers. | 18, 19 |
| Demand satisfaction | Percentage of customer orders successfully processed on time. | 4, 18, 19 |

diagram was successfully tested, we proceeded to develop the conceptual model.

5. Develop conceptual model. The final conceptual model corresponds to the successfully tested version of the causal diagram. This model is intended to be

used in further research to simulate the vinasse based LF supply chain and consequently propose implementation policies and strategies based on the results of the simulation.

# 4 Implementing the Methodology

This section discusses how we implemented the methodology introduced in the previous section in order to develop the conceptual design of the vinasse based LF supply chain.

## 4.1 Steps 1 and 2 – Identify Model Variables and Define Relationships

It is important to accurately identify the critical variables involved in the logistic processes of the vinasse based LF supply chain. The main processes of the vinasse based LF supply chain are as follows:

- Procurement. Vinasse is procured as the raw material necessary to satisfy LF production.
- Production. Vinasse is converted to LF, an animal-edible product.
- Distribution. The feed is brought to final consumers via warehouses and retailers.

Table 1 introduces the critical variables identified in the block diagram and used to build the causal diagram of the vinasse based LF supply chain. As previously mentioned, causal diagrams are a tool for graphically visualizing and defining the multiple relationships governing a system. We also considered the causal diagram of the ethanol production process, since the vinasse used for the LF supply chain is a byproduct of said process.

## 4.2 Step 3 – Block Diagram

This section uses the block diagram to analyze the interactions among the multiple links of the vinasse based LF supply chain. Namely, the diagram allowed us to identify the critical variables involved in the conceptual model. As Figure 2 depicts, the vinasse based LF supply chain initiates with the harvest of sugarcane, which is then taken to sugar mills or refineries to be processed into sugar. Molasses is generated during the sugar production process as a byproduct.

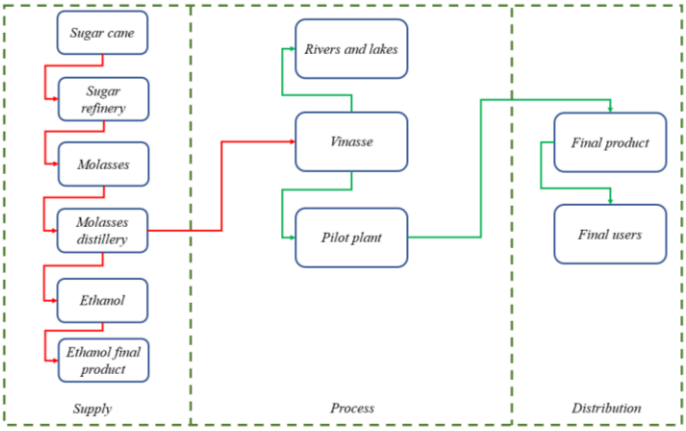


**Fig. 2.** Block diagram of the vinasse-based LF supply chain.

Even though it can be used to produce animal feed, in this case molasses is used to produce ethanol. Ethanol has applications in the make-up, medical, beverage, and biofuel industries. The ethanol distillation process produces around 11 L of vinasse per liter of ethanol. Vinasse is commonly disposed in water bodies such as local lakes and rivers, thus damaging local fauna and flora and reducing oxygen in aquatic ecosystems.

### 4.3 Steps 4 and 5 – Develop Causal Diagram and Identify Feedback Loops

Causal diagrams are graphs that help identify how the variables within a particular system interact either positively or negatively. To this end, causal diagrams rely on feedback loops connecting the system variables. Feedback loops occur as a result of the system's own complexity and can be defined as closed loops, in which a given variable has an impact on another variable, which in turns has feedback on the first variable (A⇄B). Notice that feedback loops can be either balancing (negative) loops or reinforcing (positive) loops. Figure 3 depicts our proposal of the causal diagram of the vinasse-based LF supply chain. As can be observed, the diagram comprises three balancing loops, explained as follows:

- **Balancing loop B1.** As long as Molasses Inventory (from supplier) increases, Molasses Procurement can be more efficient. Additionally, if Ethanol Production demands greater amounts of raw material, Molasses Procurement must increase, which in turn causes Molasses Inventory (from supplier) to decrease.
- **Balancing loop B2.** Ethanol Production Capacity has a direct effect on Ethanol Production, since the latter may increase or decrease as the former either increases or decreases, respectively. Likewise, larger amounts of In-Factory Molasses Inventory can increase Ethanol Production as long as the plant's infrastructure allows it. Next, as Ethanol Production soars, In-Factory Molasses Inventory decreases.

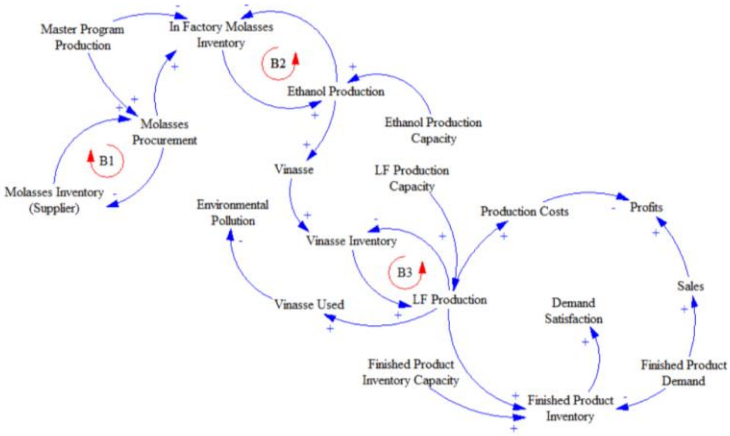


**Fig. 2.** Causal diagram of the vinasse-based LF supply chain.

– **Balancing loop B3.** LF Production Capacity has a positive effect on LF Production. In turn, any surge in LF Production causes Vinasse Inventory to decrease. As long as Vinasse Inventory levels suffice, LF Production is sustained; however, low Vinasse Inventory levels reduce or even completely halt LF Production. Notice that the more LF Production, the larger the amount of Vinasse Used, which consequently reduces Environmental Pollution.

LF Production has positive impacts on both Production Costs and Finished Product Inventory. Namely, more production leads to larger amounts of Finished Product. Similarly, as production levels soar, more resources are used; hence, Production Costs rise. On the other hand, Finished Product Demand has a direct and proportional influence on Sales. As Finished Product Demand either increases or decreases, Sales respectively increase or decrease.

In turn, Profits (i.e. revenue minus production costs) can be either positively or negatively altered as Sales either increase or decrease, respectively. In other words, larger Sales entail higher Profits, yet higher Production Costs lead to lower Profits. Also, Demand Satisfaction directly depends on Finished Product Inventory, as low levels of the latter may not lead to high levels of the former. Conversely, if inventory levels increase, Demand Satisfaction rates also increase.

### 4.4 Step 6 – Final Conceptual Model

After completing the causal diagram, we tested the causal relationships between the variables. To this end, we resorted to a panel of field experts to determine whether such relationships were representative of the system being studied – i.e. the vinasse-based LF supply chain. Next, we used the tested diagram to develop the simulation model on specialized software. The analysis of the causal diagram indicates that correct coordination among the links of the vinasse-based LF supply chain would ensure efficient vinasse utilization.

## 5 Conclusions and Future Work

This research adopts a system dynamics (SD) approach and designs a causal diagram to ultimately propose the conceptual model of the vinasse-based LF supply chain. The research confirms that SD can successfully model the multiple interactions governing a supply chain system. To this end, SD adopts a holistic approach to analyzing longer time and spatial scales.

Our conceptual model of the vinasse-based LF supply chain sets the grounds for much needed simulation models that can eventually help the research community design and assess LF supply chain systems to explore how industries can take better advantage of byproducts such as vinasse, while contributing to a more sustainable environment. However, the excessive amount of vinasse generated during the ethanol production process demands for new tools to properly coordinate the multiple links involved in the vinasse-based LF supply chain.

As future work, we will aim at validating our conceptual model within the industry by implementing it in a case study. The results of said validation would help us further develop the simulation model of the vinasse-based LF supply chain.

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# Conceptual Model of Mosquito Life Cycle Aedes Aegypti to Describe the Behavior of Dengue Virus

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**Abstract.** Mosquitoes of the species Aedes (Ae. aegypti or Ae. albopictus) can transmit Dengue, Chikungunya, Zika and Yellow Fever. For the people's mobility and increasing population density, diseases as the Dengue have been an epidemic in recent years, being a globally important health problem. Those responsible for creating vector control campaigns and medical staff are interested in identifying tools to predict the seasonal peak of the dengue outbreak and identify related climate factors that contribute to the increase in the number of mosquitoes. The main variables entered are precipitation, temperature, and epidemiological week. The model is the first phase of a project that aims to provide a tool for simulating outbreaks of dengue with system dynamics, a basis for predicting the spread of the dengue outbreak in Orizaba, Veracruz, Mexico.

**Keywords:** System dynamics (SD), simulation, dengue virus, aedes aegypti.

## 1 Introduction

The Aedes Aegypti mosquito goes through four distinct stages during the life cycle: egg, larvae, chrysalis and adult [1]. They can live in urban areas with altitudes below 2200 meters above sea level, lay their eggs in clean water tanks such as swimming pools, vases, aquatic plants, tires, buckets of water and any container that is outdoors and can store water [2]. Studies on the flight radius indicate that most females can spend their entire lives inside or around the houses in which they have become adults, and that they usually fly about 400 meters on average [3].

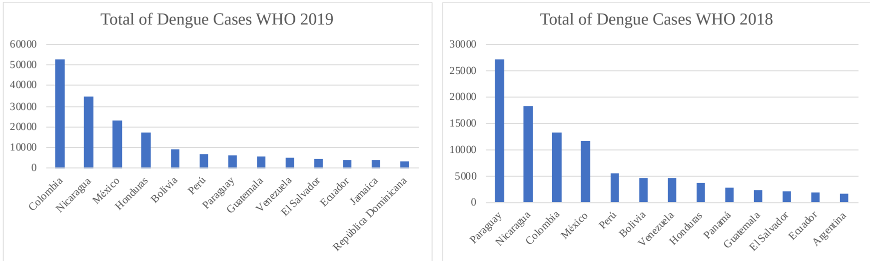


**Fig. 1.** Total of Dengue Cases, year 2019-2018.

Dengue is considered to be the most important mosquito-borne viral disease, about half of the world's population lives in countries endemic, causing it to spread rapidly, with a lethality exceeding 2% per year [4, 5], in more than 100 countries [6, 7].

The virus is transmitted to humans through the bites of infected female mosquitoes, mainly of the species Aedes Aegypti. After incubation of the virus (4 to 10 days), an infected mosquito can transmit the virus for the rest of its life. Mosquitoes usually acquire the virus while feeding on the blood of infected humans (symptomatic or asymptomatic), with humans being the only source of the virus for uninfected mosquitoes [8].

## 2 Background and State of the Art

Up until 1970, only nine countries had experienced severe dengue epidemics, currently endemic in more than 100 countries in WHO regions, accounting for approximately 70% of the global burden of disease. An estimate indicates that 390 million infections occur dengue per year (credible interval of 95%: 284 to 528 million), of which 96 million (67 to 136 million) manifest themselves clinically (with any severity of the disease). And an estimated 3.9 billion people are at risk of contracting the dengue virus [9].

The WHO collects information from ministries of health, which groups information from the Americas in six groups, on the continent a 662% increase between 2018-2019. Mexico is in the " Isthmus " group Central America and Mexico" together with Belize, Panama, El Salvador, Costa Rica, Guatemala, Honduras and Nicaragua, in the years of study, Mexico has been in second place (28%.26% respectively) of the cases reported in the group; Figure 1 shows the growth of Dengue and the relevance to Mexico and the impact on the continent (to facilitate the analysis, Brazil is excluded, which is in first place with a wide difference) [10].

The average economic cost of dengue in Mexico was $170 million in 2013, including direct and indirect costs associated with dengue. The cost associated with inpatients was $25 million, while outpatient and fatal dengue episodes account for $54 million and $8 million per year, respectively.

In addition, the monitoring cost and vectors control account for 48.9% of the total economic burden of dengue in the country, equivalent to $83 million per year [4]. In particular, average annual spending estimated for insecticide products per household

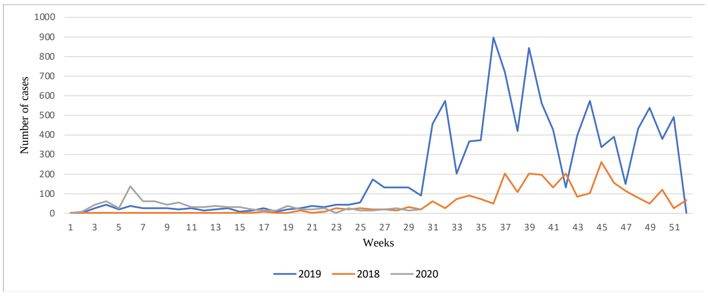


**Fig. 2.** Cases reported by the Health Department of Mexico between 2018-2020.

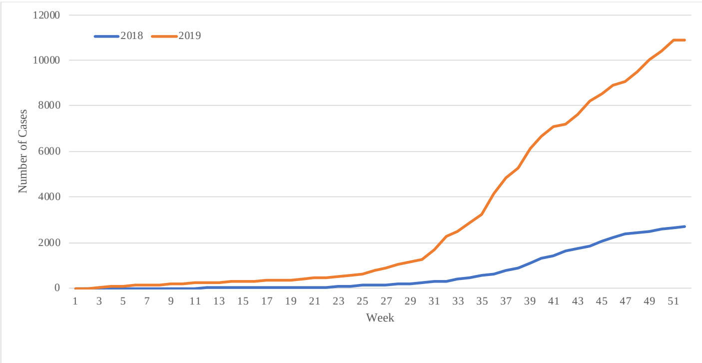


**Fig. 3.** Cases reported by the Secretary of Health of Mexico in Veracruz.

was $31 million [11]. However, vector control is partially successful in reducing the burden of dengue disease, increasing the importance of prevention [6].

The incidence has increased 303% in Mexico between 2018-2019 (see Figure 2) [12], although cases reported up to epidemiological week 30 of 2020 are shown, were not taken into account for the analysis due to irregularity caused by the SARS- CoV- 2 infection.

Having tools that allow patient estimations to be treated, make it easy the design of public vector control policies, to determine the economic impact, to build health policies in the Health Care Institution, and to prepare them for the attention of this population in terms of technology, availability of laboratory tests and human resources, Figure 3 shows the growth of the disease in the state of Veracruz.

Figure 4 shows the results of technology surveillance conducted with the keywords "Dengue model AND Simulation" in the databases ScienceDirect, Scopus, Web of Science and IEEE, finding 4034 articles, of which 327 were duplicated and 3659 were excluded for not complying with inclusion criteria (refer to aspects of care, treatment or ecology not included in the research). Therefore, only 48 articles were evaluated in full text for fulfilling the objective of the investigation, identifying that 11 of these used SD which is the proposed technique because allows to analyze and understand the underlying causes of the system studied in different scenarios, without modifying the actual system, however, of the 48 evaluated articles, were only taken 7 as a reference

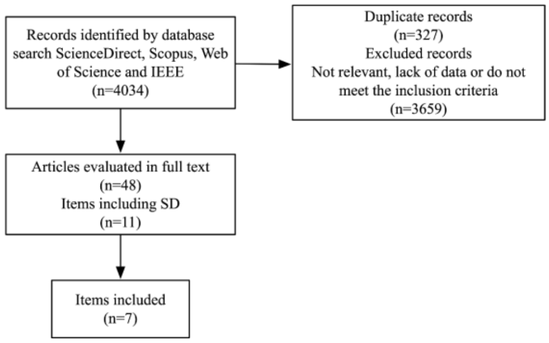


**Fig. 4.** Bibliometric analysis.

**Table 1.** Identification of variables for causal diagram design.

| Authors | Variables | Description |
|---|---|---|
| [1, 16–19] | Temperature<br>Rainfall | Temperature in Celsius degrees in Orizaba, Veracruz. Climate fluctuation contributes to the seasonal dynamics of infectious diseases because it affects pathogen transmission rates. |
| [1, 8, 16, 18, 20] | Predators | Rate of predators decreasing the population of Mosquitoes. |
| | Food | Amount of food available. |
| | Number of eggs | Number of eggs, starts with 1000. |
| | Egg mortality rate | Egg death rate per natural causes. |
| | Larvae | Number of larvae, starts with a 0. |
| | Larvae mortality rate | Death rate of larvae from natural causes. |
| | Pupas | Number of pupae, starts with a 0. |
| | Pupas mortality rate | Death rate of pupae from natural causes. |
| | Female mosquitoes | Number of female mosquitoes, 50% of the total population is assumed. |
| [16, 20] | Diapause eggs | Eggs in inactivity due to low temperatures. |
| | Egg mortality rate in diapause | Egg death rate in diapause for natural causes |

for this investigation, because they allowed identify the key variables required in the development of the causal diagram.

There are different models of transmission of infectious diseases focused on Aedes Aegypti mosquitoes, it was found that from 2015 to 2020, 135 publications have been made with the keywords "Dengue model AND Simulation", four of which have been made in Mexico, concerning the risk matrix of vector-borne diseases [13], antibodies against dengue in three urban environments in Yucatan [14] and projected impact of the vaccine against dengue in Yucatan [15]. The seasonality equations in the Aedes aegypti mosquito life cycle, were taken as basis for this model [16], because they study the effects of temperature and precipitation for eight Mexican regions and the diapause role of in seasonality shoots in conjunction with [1] to complement some parameters not detailed in the previous [16], because of the similarity between the case-of-study regions and specificity of information.

## 3 Model Formulation

The growing need to control dengue has driven the development of research to shape mosquito behavior. System dynamics allows to model different variables of propagation, control and attention that impact the behavior of the disease.

Table 1 presents the authors (first column) who have identified key variables in their investigations, which will be used with the names listed (second column) and corresponding descriptions (third column). The model is developed based on [21] for the creation of dynamic system simulation models, first the key variables are selected, the information collected allowed to identify the variables (Table 1) that represent the different interactions between the stages of the life cycle and meteorology.

The second step, which is the Formulation, different mathematics techniques that include the seasonality of the life cycle were identified, such as: Vector Modeling, Multiple Staged Regression Analysis and Analysis [1, 18, 16, 19, 20]. Some authors have used System Dynamics [17, 22], to structure the elements and programming required in Stella® software. To simulate temperature and precipitation behavior, the information available at NASA [23] over the past five years was used, the data were analyzed and with a 95% confidence level the normal distinction is adjusted, normal log, exponential and logistics.

Once the variables were identified, the Causal Diagram was developed (Figure 5), in which the main variables and the feedback loops between them are identified. The red interactions represent the stages of the life cycle, grouped into mosquito biology (egg, larvae, pupa and adult) and meteorology (temperature and precipitation), is contextualized with preventive and corrective control strategies identified in green, although these are not within the scope of the document.

The loops in the Causal Diagram are described below:

– B1: The swing loop B1, is made up of female mosquitoes, number of eggs, larvae and pupas, if the larvae increase, then there will be more female mosquitoes and each of the above variables, conditions that are conserve as long as there are no temperature changes or there are control strategies.

– B2: The B2 rolling loop, composed of Preventive control and vector surveillance and control, reflects the indirect relationship between these variables.

– B3: The swing loop B3, vector surveillance and control and corrective control and preventive control shows how when the vector surveillance and control decrease corrective control.

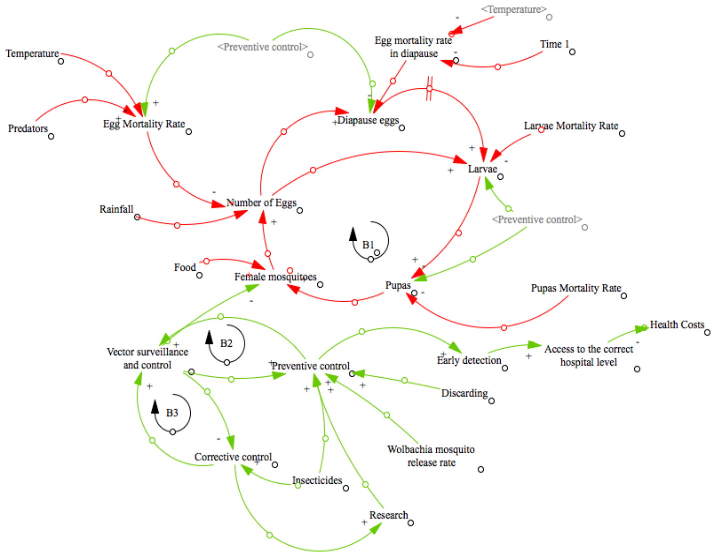


**Fig. 5.** Causal loop diagram.

The overall analysis of the causal loop diagram shows that the temperature and precipitation are key variables that influence the life cycle of mosquitoes, mortality, and diapause. If at least one is outside the life-friendly values, the number of mosquitoes at each stage will be severely affected and their future will be compromised.

Validation is intended to determine whether the structure and behavior are consistent with the cases of dengue recorded by the Secretary of Health of Mexico until the results are satisfactory. The purpose of this research is to simulate the behavior of the mosquito population with system dynamics.

For simulation, it is important the precipitation, temperature, and the total number of dengue cases per week to predict the behavior of dengue-transmitting mosquitoes. This is an archetype that can be used in other countries for any period of time if fed with information from the region to be studied.

## 4 Conclusions and Future Work

A deterministic model can be used to understand the dynamics of disease transmission, particularly for large populations. Using the dynamic system approach and causal loop diagram, this research proposes a conceptual model that analyzes the biological process of mosquito reproduction, taking into account death rates related to environmental factors, which allows future analysis of biological, chemical or mechanical control activities and how this relates to the dynamics of Dengue.

This model can be complemented by integrating diagnostic stages, the capacity of the health care institution, days of disease evolution when going to a medical service, the available equipment, among others. This will provide a better understanding and a more complete vision to find opportunities for improvement. Vector control and health care processes continue to be investigated in Orizaba, Veracruz, Mexico.

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# Dynamic Simulation to the Beekeeping Supply Chain in the Region of Vichada, Colombia

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**Abstract**. The purpose of this article is to model beekeeping production in the region of Vichada in. The beekeeping chain was chosen as the objective of the study because it is a sector of economic importance in the mentioned region with the highest indices of multidimensional poverty in Colombia, but also one of the places with the greatest conservation of its biodiversity. A systems dynamics approach is used from a causal diagram to explain the interactions among bee rearing, wax production, honey production and transformation, and then simulations were performed to determine the behavior of inventories with respect to the production and demand. This model highlights the dynamics of the system and the management of the supply chain and is presented as a useful tool to predict production-demand scenarios in the beekeeping sector where similar studies are scarce. As future research, it is recommended to include the economic nature of the products in this kind of models so that scenarios can be proposed to help beekeepers make production decisions according to demand and develop inventory policies.

**Keywords:** Honey, wax, system dynamics, product diversification.

## 1 Introduction

The beekeeping supply chain involves the rearing of bees, the products derived from the hive and their relationship with the demand, in which many participants are linked. The science of caring for bees considers the production environment with the availability of honey flora and agents that can cause mortality in bees, as well as the productive purpose of the beekeeper for which hives are used which are made of wooden boxes with frames. They contain wax cells built by bees and are used to store food made up of honey and ¿pollen.

All these elements that combine within the hive are used by the beekeeper to extract and market them, and even the same bees are sold as biological packages, although keeping a minimum population of bees within the hive to avoid an imbalance. Vichada

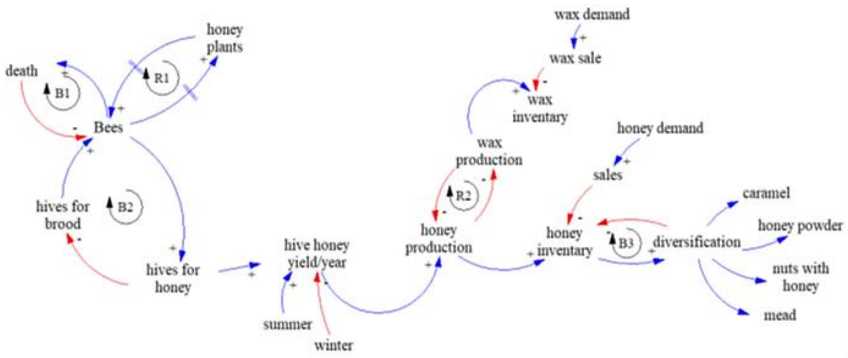


**Fig. 1.** Causal diagram of Beekeeping production.

has about 95.940 forest hectares within which are plantations of Acacia mangium that provides nectar for bees (El Espectador 2020). In this region, the river Bita basin, with a Ramsar wetland declaration that preserves a natural landscape, contains 1.474 specimens of plants, belonging to 103 families, 278 genera and 424 plant species

(Trujillo and Lasso 2017) and at the same time it provides clean water and food for bees and an adequate environment for the development of the beekeeping chain.

For regions with a tropical climate such as Vichada, honey is the main product of the hive. Vichada has an approximate production of 140,000 kg of honey with yields of 40 kg / hive-year. Beekeeping is prioritized as one of the productive bets of the region (Comisión Regional de Competitividad e Innovación de Vichada 2019) due to the apicultural potential given by the environmental conditions and botanical resources for the development of the activity (Castro 2018).

However, nowadays this sector presents the need for investigating at a higher extent the bee chain, its products and innovative uses to generate value (Ministerio de Agricultura y Desarrollo Rural 2018). This coincides with the low competitiveness of bee honey production in Vichada, which influences the inappropriate existing inventory.

Therefore, it is intended to evaluate honey production in terms of its dynamic demand, and it seems convenient to establish production systems that consider other kinds of products such as bees for breeding, and by-products derived from honey, and wax. The latter one, has an interesting demand by beekeepers and pharmaceutical industry mainly and also bees have a demand related to recover degraded agroecological systems or support agricultural productions that require the pollination service provided by bees.

In this sense, system dynamics is presented as a useful tool to represent problems and provide solutions to a given situation, through a relationship of variables and simulation of the built model. When conducting a preliminary review using the Scopus database considering English written articles relating system dynamics and the word honey, only 12 articles were found that were reviewed and some limitations were found in the form that authors face the system dynamics modeling in a beekeeping context.

Carlevaro et al. (2004) present a conceptualization and simulation with system dynamics of the behavior of the Argentine honey chain with an export profile and analyze climatic, economic, and technological scenarios.

However they do not present a Forrester model that allows readers to replicate the model. Ward and Boynton (2010) used an econometric model to analyze the honey demand and showed the impact of its generic promotion, and Rusell et al. (2013) evaluated the factors that may have the greatest influence on the growth and survival of the colonies but the products of the hive were not considered.

Therefore, there are few known studies of system dynamics in bees or in honey production in the Colombian and Vichada context that lead to having a model that considers productive factors of the hive and its by-products that opens the possibility of evaluate a wider range of decisions in the beekeeping chain. This aspect reflects the innovative component of this article which aims to develop a dynamic simulation model to evaluate beekeeping production in Vichada.

## 2 Methodology

The case study was the beekeeping production model in the region of Vichada, Colombia. The conception and construction of the model was carried out in Vensim PLE.

### 2.1. Causal Diagram

The Figure 1 presents the causal diagram that indicates the cause-and-effect processes originated in the dynamic behavior of beekeeping contexts, and this is based on the literature review and on the knowledge of beekeeping experts in Vichada. The arrows in the diagram are used to link the causal elements and the sign used symbolizes the direction of the effect generated by the cause. Feedback loops are also employed, with a reinforcing or compensating nature. Figure 1 contains two reinforcement loops and three compensation loops.

During the visit of the bees to the plants in search of nectar, they carry out pollination, which would cause the growth of more honey and nectariferous flora, that is, R1 has double delay. For the R2 loop, as wax production increases, honey production decreases.

In addition to the nectar supply, the reproduction of bees is influenced by mortality, loop B1, and if this mortality of bees is high then the population of bees decreases significantly. The compensation loop B2, means that if the number of bees in a hive increases significantly, then the beekeeper can increase the boxes, vertically in the same hive for honey production, but at the same time reduces the possibility of dividing colonies of bees for breeding (Jimenez 2017). However, the number of bees continues to increase. Regarding the B3 loop, as the diversification of products from honey increases, the inventory of honey decreases. By having honey-producing hives, the hive / year yield increases, expressed in kg of honey / hive, which is mainly influenced by the harvest season (Medina et al. 2014).

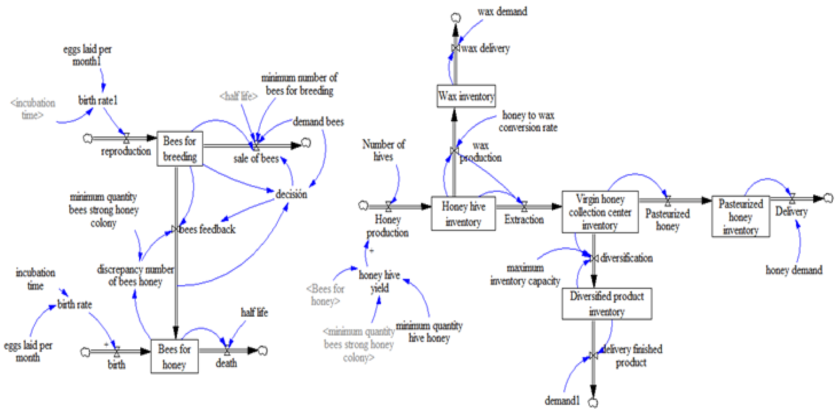


**Fig. 2.** Forrester diagram of the beekeeping production in Vichada.

If the honey yield increases, so will the honey production in the hive. Although here it can be presented that the honey is converted by the bees into wax, if there is a demand for wax, it increases sales and therefore the inventory of honey decreases. Honey production can be extracted from the hive and ante resultant inventory is affected by sales which are influenced by demand. The beekeeper, then, can follow a line of product diversification based on honey. In the context of Vichada, honey is used as raw material for the production of alcoholic beverage mead (Hernández et al. 2016), and it is also used as a coating for cashew nuts, and it is marketed in doypack bags and in glass containers with dispensers, as a strategy to reduce honey inventory.

## 2.2. Data for the Model

In addition to the loops already presented, relevant information to the model was obtained for testing: it was considered a minimum number of bees for breeding, a weight of 1 kg of bees which implies between 10.000 and 12.000 bees. However, a strong and healthy colony has at least 5 kg of bees, with an incubation time of the bee in the breeding cell on average of 21 days, and it is estimated that a queen bee on average has a posture of 500 eggs/day in winter season and up to 1500 eggs per day in summer.

The half-life of the queen bee is 3 years and of the worker bees with beekeeping of up to 25 days in winter, and 19 days in summer which is the time when the flowers expel nectar and provide pollen and therefore the bees work harder in winter to collect and store food. In the harvest season the beekeeper visits the hive and extracts hive boxes with honey, but they should leave a minimum amount of honey for internal food of the bees, which is about of 5 hive boxes with honey, 6 kg of honey (Director técnico Apícola de Inverbosques S.A.S, Manuel Bernal, Puerto Carreño-Vichada, comunicación personal, 2020).

As for the conversion rate of honey into wax, it is necessary 8 kg of honey to produce 1 kg of wax, and this occurs in the wax glands of the abdomen of bees (Monreal 2019).

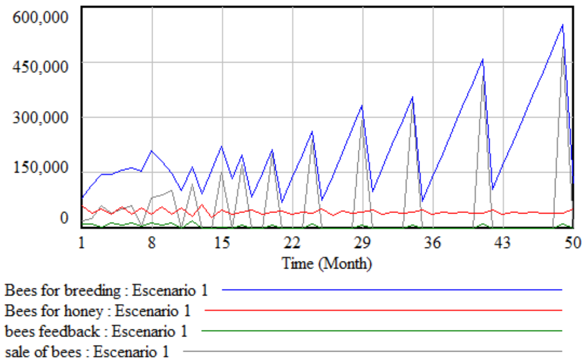


**Fig. 3.** Comparison between bee levels and feedback and sales outs flows.

Although wax is an indispensable input for developing beekeeping activity and therefore has a commercial demand, the demand for wax is not known for certainty and in this article is considered a behavior of a uniform distribution between 10 and 1000 kg. For the demand of pasteurized honey, the consumption culture of 0.83 g honey per person in Colombia is accounted for (Ministerio de Agricultura y Desarrollo Rural 2019), and we assume a behavior of a normal distribution of 6.500 to 7.778 kg of pasteurized honey/month.

It is also taken into account that the quality of the product of Vichada's extrafloral honey is supported by studies of the physicochemical composition and known sensory and bioactive attributes, and the extraction process is carried out in compliance with good handling practices (Castro 2018).

With regard to the products diversification from honey as a raw material or input, we assume that there is a qualified workforce in the region, equipment and inputs are available to transform the products, and also storage capabilities are available for the processed products. It is considered to have a demand with normal distribution behavior of 2.500 to 2.121 kg of diversified product/month. The system dynamics model includes level variables, flow variables, and auxiliary variables represented in Figure 2.

## 3 Results

The interpretation of the model expressed in the Forrester diagram is presented from left to right. A first scenario (Figure 3) was analyzed that corresponds to the breeding of bees and hives for honey in summer season where the half-life of the bees is 19 days because there is flowering in the plants and the worker bees leave the hive to perform pecoreo work, and this process is performed from 4:30 am to 6:30 pm approximately in Vichada.

It is also considered an impact on hives from attacks by animals such as the Plain Ocarro or Armadillo which consume bee and honey larvae, as well as the burning of Vichada savannahs that reach forest plantations and cause the escape of bees

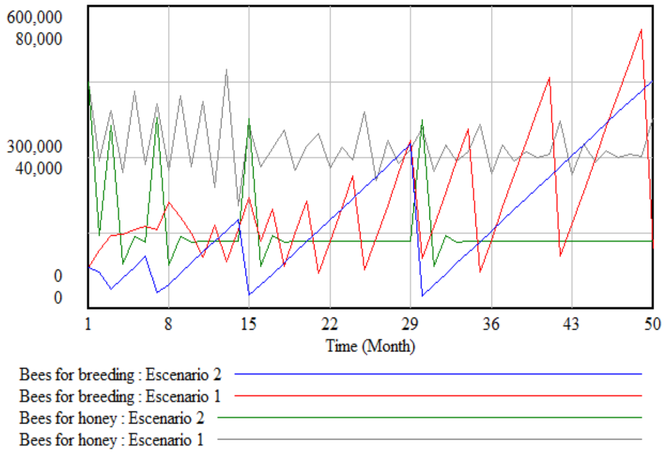


**Fig. 4**. Behavior at the level of bees for breeding and honey bees in two scenarios.

(Asociación de Apicultores y Meliponicultores de Vichada, comunicación personal 2020).

Other factors are considered in a lesser proportion, based on the literature, such as exposure to pesticides (Klein et al. 2017), malnutrition of the colony (Naug 2009; Montoya et al. 2016), diseases and parasites (Potts et al. 2010),which according to the reviewed literature, these are important factors in the mortality of bees. Likewise, the queen bee is considered to increase its egg posture to try to compensate for the bee population.

Figure 3 shows the behavior of the "Bees for breeding" and "bees for honey" inventories and the variables "sales of bees" and "bees feedback", where there is a slight increase in bee reproduction until the eighth month and then a decrease that coincides with the behavior of salts of bees.

It also shows a fluctuation in the amounts of bees for breeding that follows typical inventory behavior based on the sale of bees and the bee dispatching for feedback of honey hives, without affecting the minimum number of bees that must be in a breeding hive. As for honey hives, they have a stable bee population because they continually receive feedback from the inventory of bees for breeding.

Figure 4 exhibits a comparison between Scenario 1 and Scenario 2. The scenario 2 is based on beekeeping behavior in the winter season where bee posture decreases to 500 eggs per day and the half-life of bees increases to 25 days. The population of breeding bees and honey bees tends to be lower in the winter (blue line) compared to the summer (red line).

Figure 5 presents the production of honey in the hive that generates an inventory of honey which fluctuates according to the output of hive boxes with honey for extraction and to the production of wax that occurs internally in the hive, but which decreases the inventory of honey.

Figure 6 shows the behavior of the "virgin honey collection center inventory" from which comes a flow of honey to pasteurize and honey to be transformed into other

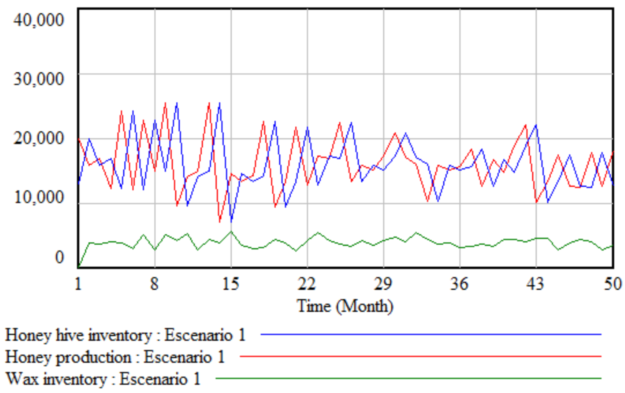


**Fig. 5.** Behavior in the honey inventory of the hive and wax inventory, and honey production.

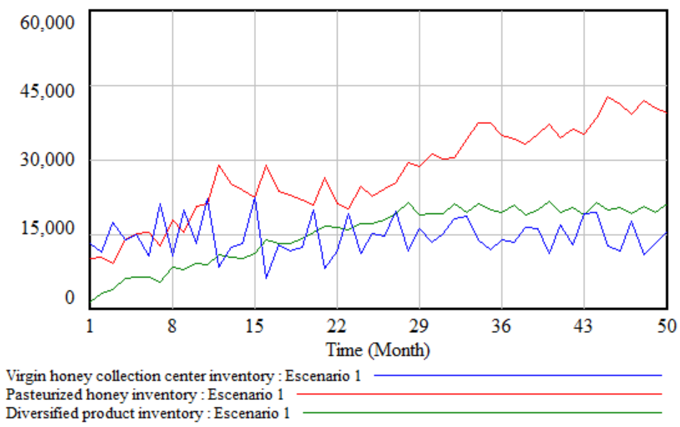


**Fig. 6.** Inventory behavior of pasteurized honey, collection center honey and diversified product inventory.

products, that is "diversification", in a ratio of 80:20. Virgin honey inventory fluctuates each month because there is an input from the apiaries and an output to the pasteurization and diversification processes, where pasteurization inventory presents a build-up based on demand that is not enough to maintain a stable inventory, and the same is true for diversification where the product diversification order depends on the storage capacity of the inventory.

## 4 Conclusions

The production of bee honey and wax depends directly on the performance of the hive which in turn is influenced by the half-life that is strongly related to the degree of health, the bee population, and the clean environment where the bees are located. Product diversification is a strategy to help reduce virgin honey inventory when low demand for honey is presented for direct consumption.

It is important to have clarity on the demand for pasteurized honey, diversified product, wax, and bees for breeding to establish production conditions and not have some accumulated inventories, while other inventories are low. It is recommended to introduce into the analysis the production costs, sales prices, and profitability of each analyzed product in this model of beekeeping production, in order to have a sustainable approach and to be able to make decisions regarding production.

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# EMA: Electronic Medical Assistant

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**Abstract.** Diseases such as asthma attacks, stomach infections, common colds, and throat and ear infections are common diseases presented by pediatric patients in public and private primary care doctor's office. The initial examination protocol of the physicians who attend these patients consists of a review of organs such as eyes, nose, throat, heart rhythm, lung and intestinal sounds and temperature. This review should provide the physician with sufficient information to determine if it is a case that requires urgent medical care or not. This document presents the design of EMA, an Electronical Medical Assistant who, based on sensors and an Arduino, obtains data directly from the patient. EMA could be used in two main scenarios; the first one is when the patient is at home and the data is sent to the doctor in order to receive a medical advice. The second one is when the patient is waiting at the hospital; a nurse read his/her data using EMA and sends it to the doctor who will decide the kind and order of the attention. The methodology consists of dividing the project into work packages, assigning to each one the activities corresponding to each of the project modules.

**Keywords:** Common diseases, pediatric patients, primary health care, Arduino, electronical assistant.

## 1 Introduction

Much of the care provided in health centers in the area of family medicine is given to pediatric patients, children between the first days of birth and 12 or 13 years of age. In the case of adults, this is a bit different since many of them avoid going to medical care for minor situations, for example common diseases such as flu, fever, and stomach conditions, among others. This is because, in most cases, the adults themselves resort to some other solution, which sometimes includes self-medication so as not to suspend their daily activities. In the case of pediatric patients, health problems require more attention, since something that might not be serious, such as dehydration or respiratory diseases, due to lack of timely care may be aggravated and have fatal consequences.

In addition, unlike in adults, in children self-medication is usually a much more delicate subject. When it comes to patients in the first few months of birth, the situation is even more complicated, first because of the fragility of their health due to their early age, and secondly because of their inability to communicate. In addition, this is complicated by the lack of experience of the parents, who also in many cases are young.

When a health problem occurs in pediatric patients, for example, a common cold, taking the child away from home could complicate the situation due to climatic changes and even pollution, and on the other hand, it involves long hours of waiting to be attended at a health center. In a situation like this, the transfer could be considered as unnecessary. Given this situation, what this document proposes, is to have a medical assistant for pediatric patients. This problem is addressed from two important points of view. The first is to try to solve the problem of unnecessary transfers, for which it is necessary to carry out the examination of the child at home and send to the doctor the results of such exploration.

The second is to allow parents to perform the osculation in a simple way. That is, it is known that the exploration in children is sometimes complicated, especially in children between 3 and 9 years of age, since in the doctor's office is performed by a strange person who is unfamiliar for the patient. To try to counter this problem, it is intended that the medical assistant has a friendly way in order to facilitate interaction with the child. The rest of the document is divided as follows: Firstly, the background and the origin of the problem of this proposal are presented in detail. Subsequently, the general objective and the specific objectives are presented.

Next, the theoretical framework section is presented, which presents the current situation of the technologies needed to develop the project, and studies and research that have been carried out and revolving around similar problems. Subsequently we present the impact or benefit that the development of this project will have, followed by the section of methodology that shows the description of the development phases realized for the achievement of the objectives.

## 2 Related Work

Use of an electronic medical record improves the quality of urban pediatric primary care was presented in [1]. This initiative allows to evaluate the quality of pediatric primary care, including preventive services, before and after the introduction of an electronic medical record (EMR) developed for use in an urban pediatric primary care center. Similarly, a study about physician assistant management of pediatric patients in a general community emergency department was presented in [2]. A pilot study, in order to enhance a pediatric CDSS (Clinical Decision Support System) with an electronic tablet based user interface and evaluate it for usability as well as for changes in patient questionnaire completion rates was presented in [3]. A system, called the Electronic Medical Record Search Engine (EMERSE) was presented in [4]. It functions similar to Google but is equipped with special functionalities for handling challenges unique to retrieving information from medical text.

The use of Electronic Health Record (EHR) documentation by healthcare workers in an acute care hospital system was presented in [5]. In this work, authors examined what information is used by clinicians, how this information is used for patient care, and the amount of time clinicians perceive they review and document information in the EHR. In [6], a general architecture of a health care system for monitoring of patients at risk in smart Intensive Care Units was presented. The system advice and alerts in real time the doctors/medical assistants about the changing of vital parameters or the movement of the patients and also about important changes in environmental parameters, in order to take preventive measures.

A novel IoT-based mobile gateway solution for mobile health (m-Health) scenarios was proposed in [7]. This gateway autonomously collects information about the user/patient location, heart rate, and possible fall detection. Moreover, it forwards the collected information to a caretaker IPA, in real time, that will manage a set of actions and alarms appropriately. The algorithms used for each mobile gateway service, and the scenarios where the mobile gateway acts as a communication channel or a smart object are also addressed by the authors initiative.

Unlike to analyzed works our initiative presents an Electronical Medical Assistant, named EMA. EMA, that it could integrating to works [1, 5, 6 and 5] and it could be used when the patient is at home and the data is sent to the doctor in order to receive a medical assistance and if the patient is waiting at the hospital, and nurse analyzes the data through EMA System and sends it to the doctor who will decide the kind and order of the attention.

## 3 EMA Architecture Description

We have decided to call this EMA (Electronic Medical Assistant) assistant. This medical assistant is presented as a robotic electronic device equipped with sensors focused on the measurement of vital signs that are commonly read in pediatric patients in a general medical practice. That is, a set of sensors that capture the temperature, the sounds emitted by heart and lungs, and images of eyes, nose, and throat, and, through a digital platform, send them to the family doctor for analysis and determine the actions to be taken, without implying the transfer of the patient.

Although EMA is geared towards the care of pediatric patients, because somehow, moving from home to a health center is complicated, sometimes unnecessary, or sometimes not recommended, it can also be used by other types of patients. Patients with different ages. This project has the additional advantage of being able to monitor the patient’s health status in a constant way, since thanks to it; the patient’s data can be collected at any time, which allow analyzing its evolution in shorter periods. An additional problem that this project also tries to attack is the auscultation of pediatric patients, since the review is often complicated due to children’s fear of doctors.

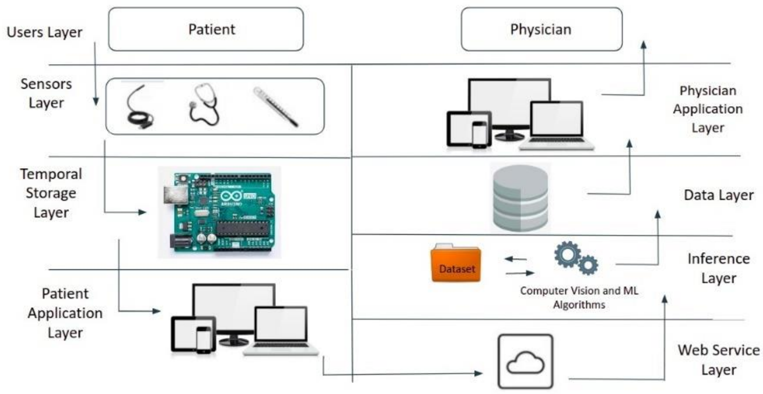


**Fig. 1**. EMA Architecture Patient to Physician.

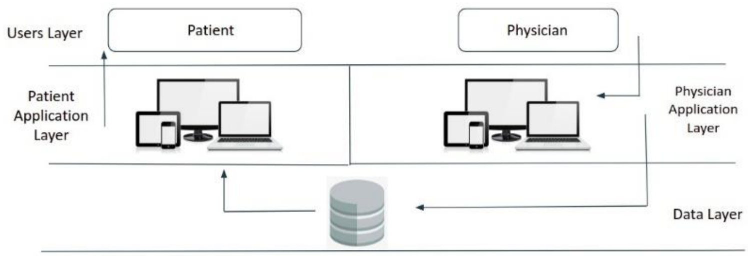


**Fig. 2**. EMA Architecture Physician to Patient.

Therefore, it is thought that if an electronic device in the form of a robot that simulates a toy performs this activity, the child will feel more confident and will facilitate their review. The architecture of this device will be conformed by an Arduino device that will have connected the different sensors that capture the information on the health of the patient.

This device should have the ability to connect to the Internet to send this information to your family doctor, who will receive it through the digital platform Medic-Us presented in [8]. Additionally, we plan to develop a module that is added to the social network and serves for the interpretation of sounds emitted by patients and captured by sensors using signal processing techniques, and thereby provide a clearer idea to the physician about the normality or anomaly of the sounds, and that this information is useful to the doctor to determine the actions to be taken.

Finally, in case the device can not send the data over the Internet, it will be provided with the capacity to store the data collected in an external storage device, for example, a USB memory for later sending using another device. The EMA architecture is presented below and is shown in Fig. 1 (Data flow patient to physician) and Fig. 2. (Data flow physician to patient)

The EMA architecture starts with the patient which is sensed by three kinds of sensors; the first one is a camera to take pictures of the patient's eyes, nose, throat, or any other sign that can be captures in a picture, for example, something in the skin. The

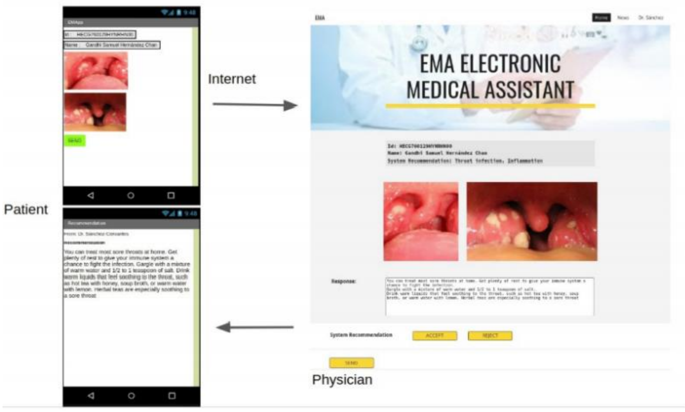


**Fig 3**. EMA use case.

second one is a sound sensor that captures different kind of sounds, for example lung, stomach, and bowel sounds. Finally, the third sensor is a temperature sensor that captures the temperature of the patient. All the data captured by the sensors layer is send to an Arduino device.

The Arduino device must send the data to the Patient Application Layer that can be a mobile device or a PC device. This can be done in three different ways, using a Bluetooth module, using a Wi-Fi module, or storing the data in a USB and then connect it to the PC. The Patient Application Layer send the data to the Inference Layer though the Web Service Layer.

The Inference Layer is composed by a Dataset which contains images to compare with, and an inference engine supported by computer vision a Machine Learning algorithm in order to make classification tasks. Then, the patient data and the result of the inference engine are stored in the Database (Data Layer) and presented in the Physician Application Layer.

Once the physician has analyzed the patient data he can communicate with the patient and send the result using the Physician Application Layer. The response will be stored in the Database (Data Layer) to allow the patient access it though the Patient Application Layer.

## 4 EMA Use Case

The mobile application is divided in two parts as it is shown in the left side of the picture. In the first part the patient takes pictures and load into the mobile application. The pictures can be taken from an external camera as it was shown in the architecture figure or from the mobile camera. Once the pictures are loaded, the patient can send it by Internet to the physician. As shown in the architecture, the images go through the image analysis engine for classification. Based on the result of the classification, the system generates a recommendation. The physician receives the patient information, images, and system recommendation in the web application, as shown on the right side of the figure.

The doctor accepts or rejects the recommendation of the system. Based on this answer, the images will be stored in the repository with the corresponding classification. The doctor writes his recommendation to the patient and sends it to him. The patient receives the doctor's recommendation in the mobile application. For each of the interactions between patient and doctor, a record is stored in the database in order to generate the patient's history and to be able to observe the evolution of the case.

## 5 Conclusions

The impact of the development and application of this technology has several aspects. On the one hand, the direct benefit to the parents of patients by allowing them not to transfer the patient unnecessarily but still, to be able to receive the health service and medical advice. On the other hand, the benefit to the patients, regardless of their age since they can be monitored from their home continuously or at least in shorter intervals of time.

In the same way, doctors obtain the benefit of knowing the health status of their patients and storing this information, which will allow them to know better their evolution, and to have information that serves as part of the medical history. In addition, having systems that compare the data obtained from a patient and the parameters considered as normal, for example, in the case of pulmonary sounds or heart rate, will enable physicians to offer a better diagnosis and for therefore a better treatment. Hospitals, clinics, and other health centers will benefit from having fewer people in their waiting rooms and thus be able to offer a better service.

## 6 Future Work

As a future work we intend to add to EMA artificial intelligence capabilities to perform two main activities. The first is image recognition using computational vision techniques such as those presented in [9] and [10] using OpenCV libraries, for the purpose of identifying abnormalities related to redness of the eyes, inflammation of the throat, etc. For this, an image repository and a system training process should be provided. The second activity is the treatment of signals.

The signals will be obtained from the sounds of the heartbeat, lungs and stomach and intestinal noises. As in the previous case it is intended to develop a system that, based on a repository of sounds and training process, be able to recognize abnormalities in the signals generated by the sounds. Also, we are interested in build computational models that can classify diseases based on patient symptoms and use these models in a space-time context in order to address epidemiology issues.

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# Fuzzy QFD to Risks Prioritization in the Reverse Logistics of Lead-Acid Batteries

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**Abstract.** This work prioritized the operational risks present in the reverse logistics of lead-acid batteries in Colombia using the FQFD (Fuzzy Quality Function Deployment). The need arises due to the high exposure of people and the environment caused by the batteries' lead residues. Since their high lead composition makes them a source of pollution, as this element is categorized by WHO (World Health Organization) as one of the ten most dangerous chemical elements in the world, and one of the most harmful to the Colombian population. We identified operational risks in the reverse logistics of lead batteries and a probability-impact matrix to define which of these risks should be prioritized with FQFD. In this way, we established the priority of the risks considered. These prioritized risks will help organizations related to this activity to develop action plans to mitigate or eliminate these risks.

**Keywords:** Lead-acid batteries, operational risk, fuzzy-QFD methodology, reverse logistics.

## 1. Introduction

According to (Li et al. 2016), with the increasing demand for Lead-acid batteries (LABs), the amount of lead-acid waste batteries (WLABs) has unavoidably increased. Accordingly, the contamination caused by lead and lead-containing compounds from these WLABs has risen to a new level. Otherwise, Lead-acid batteries were widely used as a power supply in vehicles, uninterruptible power supply (UPS), telecommunication systems, and various traction duties. According to statistics, approximately 3 million tons of waste batteries are generated every year. Lead-acid batteries' production will continue to rise even more sharply with the economy's sustained and rapid development. Lead-acid batteries are composed of electrolyte, lead and lead alloy grid, lead paste, organics, and plastics, including lots of toxic, hazardous, flammable, explosive substances that can easily create potential risk sources (Zhang et al. 2016).

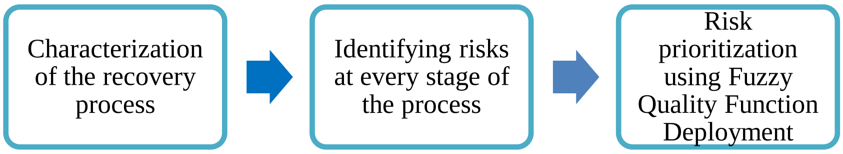


**Fig. 1.** Methodological design.

On the one hand, according to (Govindan et al. 2017), reverse logistics networks (RLN) are often designed to collect used, refurbished, or defective products from customers and then carrying out some recovery activities. The reverse logistics issue is to take back the used products, either under warranty or at the end of use or the end of the lease, so that the products or parts are appropriately disposed, recycled, reused, or remanufactured (Kannan et al. 2010). But in this case, one of the most important aspects are related to the complex issues depending on social, technical, and legislative factors are: how to prevent the environmental deterioration caused by the generation of hazardous wastes, how to minimize the generation of hazardous wastes, and finally how to recover the valuable material contained by the wastes (Jayant 2015).

On the other hand, operational risk has gained increasing attention in academic research and practice because operational risk directly affects the company's economic results. Due to the influence of risk on logistics performance, implementing risk management has become a critical aspect, and the reverse logistics process is not exempt from operational risks. These situations can affect companies by generating significant economic losses due to sanctions, fines, and compensation, as well as being passed on to the environment: soils, air, and water bringing fatal consequences on the health of people and ecosystems. That is why identifying and prioritizing these risks can be a fundamental activity in establishing actions that are oriented to preserve the health of the people involved in these processes and avoid harmful effects on the environment derived from lead.

## 2. Methodology

The methodological design for the development of the project is presented below in Figure 1. The methodology will have three phases:

### 2.1 Characterization of the Recovery Process

It is essential to characterize the reverse supply chain for the recovery of lead-acid batteries, additionally, to identify the processes necessary for this recovery. In this way, with the chain characterized and the processes identified, it will be possible to determine their operational risks.

**Table 1.** Linguistic scale for the risk identification and fuzzy equivalence for FQFD (Pastrana-Jaramillo and Osorio-Gómez 2018; Osorio-Gómez et al. 2019).

| Linguistic Scale | Very low (VL) | Low (L) | Medium (M) | High (H) | Very high (VH) |
|---|---|---|---|---|---|
| Numerical equivalence | 1 | 2 | 3 | 4 | 5 |
| Triangular fuzzy number | (0,1,2) | (2,3,4) | (4,5,6) | (6,7,8) | (8,9,10) |

## 2.2 Identifying Risks at Every Stage of the Process

According to (Aqlan and Lam 2015), risk identification is the most important activity in the supply chain risk management system. We use the methodology presented in (Pastrana-Jaramillo and Osorio-Gómez 2018; Osorio-Gómez et al. 2019), a literature review, and application of questionnaires to experts; we identified the main risks associated with the battery recovery process shown in figure 3. The questionnaire's application was carried out individually and allowed the experts to rate the risk, both in probability and impact, using the linguistic scale illustrated in Table 1. In the same table is presented the numerical equivalence used in the prioritization stage.

The data obtained apply Equation 1 and Equation 2 to get the percentages of risk application and weighted averages of the occurrence probability and magnitude of impact (Pastrana-Jaramillo and Osorio-Gómez 2018; Osorio-Gómez et al. 2019):

$$\overline{\mathrm{X}}_i = \frac{\sum_{j=1}^{n}(\mathrm{B}_{i,j} \times \mathrm{M}_{i,j})}{\mathrm{n}}; \ \forall\, i, \quad (1)$$

$$\overline{\mathrm{Y}}_i = \frac{\sum_{j=1}^{n}(\mathrm{B}_{i,j} \times \mathrm{P}_{i,j})}{\mathrm{n}}; \ \forall\, i. \quad (2)$$

$X_i$ = Weighted average of the magnitude of risk $i$
$Y_i$ = Weighted average probability of risk $i$
$B_{(i,j)}$ = Expert's criterion $j$ if $i$ applicable as risk $(1,0)$
$M_{(i,j)}$ = Expert's qualification $j$ on the impact of risk
$P_{(i,j)}$ = Expert's qualification $j$ on the probability of risk $i$

After getting these data, we built the Impact Matrix. We use the following terminology per section: green are negligible risks, while yellow and red are critical. The latter are the ones selected for the next phase.

## 2.3 Risk Prioritization Using Fuzzy Quality Function Deployment

Risk prioritization is fundamental to success in defining actions to mitigate or eliminate risks. In this sense, it is crucial to determine this priority based on the companies'

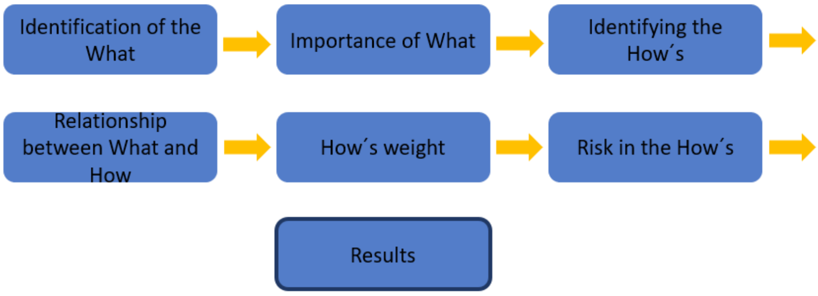


**Fig. 2.** Fuzzy Quality Function Deployment to risk prioritization (Osorio Gómez et al. 2017).

strategic objectives so that the risks directly impact these objectives so that these are the first to be treated. Some papers use QFD y FQFD in supply chain management and risk management such as (Bevilacqua et al. 2006; Wang et al. 2007), and especially (Gento et al. 2001; Costantino et al. 2012; Lam and Bai 2015) are focused in risk management, but these applications are not with fuzzy logic and are not to risk prioritization. The Fuzzy QFD methodology for risk prioritization is shown in Figure 2. This is according to (Osorio Gómez et al. 2017).

## 3. Results

Following the methodology presented above, the next results were obtained.

### 3.1 Characterization of the Recovery Process

Figure 3 present the typical reverse logistics network to lead-acid batteries and figures 4 and 5 show the process of recovering lead-acid batteries. The next phase is to identify the risk in each of the processes.

It is essential to mention that this type of chain typically shows four actors: the producers of the batteries, the distributors of them, the users (who be-come the suppliers of the reverse logistics process once the batteries end their useful life), and those responsible for the collection, transport, and recovery that for this work we call them third parties, as shown in Figure 3.

### 3.2 Identification of Operational Risks

Table 2 presents the identified risks and the results of the application of the questionnaire. Figure 6 shows the probability impact matrix. In this case, the risks that continued to the next stage are R4, R5, R10, R12, and R13.

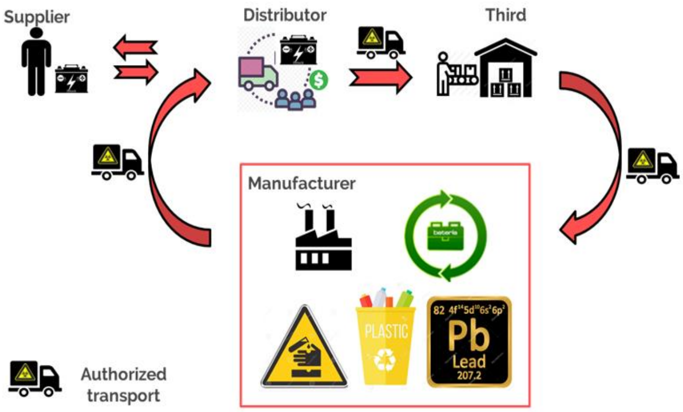


**Fig. 3.** Reverse logistics network to lead-acid batteries.

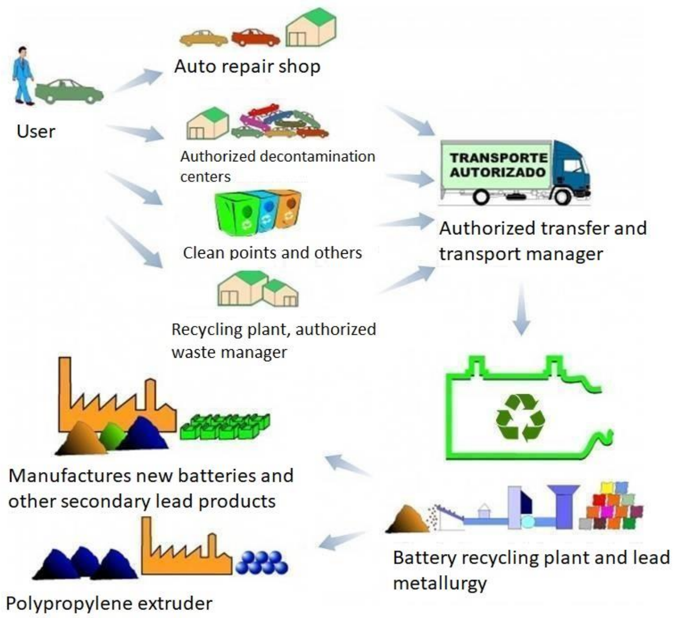


**Fig. 4.** The battery recovery process in a Colombian company.

### 1.1 Prioritization of Operational Risks

Following the methodology presented, Table 3 shows the WHAT´S and its importance. We used the triangular fuzzy numbers presented in Table 1.

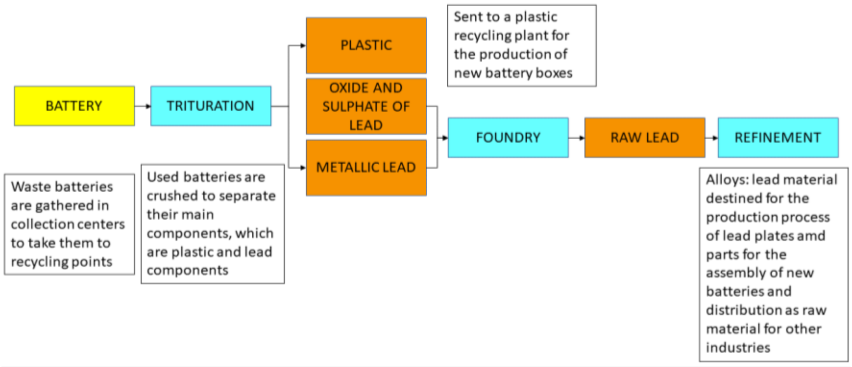


**Fig. 5.** Battery recovery process.

**Table 2.** Validation and weighted averages of operational risks.

| RISK DESCRIPTION | ID | PROBABILITY OF OCCURRENCE | IMPACT |
|---|---|---|---|
| Sulphuric acid spills in collection and transport | $R_1$ | 2,13 | 2,25 |
| Lead leaks that are incorporated into the soil | $R_2$ | 1,13 | 1,75 |
| Electrolyte spillage (sulfuric acid) in rivers or lakes | $R_3$ | 1,38 | 1,88 |
| Manual battery handling | $R_4$ | 3,00 | 3,50 |
| Soil and environmental pollution from surrounding areas | $R_5$ | 2,50 | 2,63 |
| Dust released from shredders and mills | $R_6$ | 1,38 | 1,63 |
| Inhalation of lead settled in the vibration equipment | $R_7$ | 1,75 | 2,25 |
| Water pollution | $R_8$ | 1,50 | 1,50 |
| Lead dust from process water | $R_9$ | 1,13 | 1,13 |
| Release of fragments and lead dust at the recycling plant | $R_{10}$ | 2,25 | 2,50 |
| Inhale lead vapor | $R_{11}$ | 1,75 | 1,88 |
| Contaminated dust in the screening | $R_{12}$ | 2,38 | 3,00 |
| Poor knowledge about lead toxicity and its management | $R_{13}$ | 2,75 | 3,13 |

Continuing the proposed methodology, the How´s and their relationship with the What´s were established to obtain the Weight of the How´s. Table 4 presented these. And finally, in Table 5, the results of risk prioritization are obtained. In this case, the most critical risk is insufficient knowledge about lead toxicity and its management.

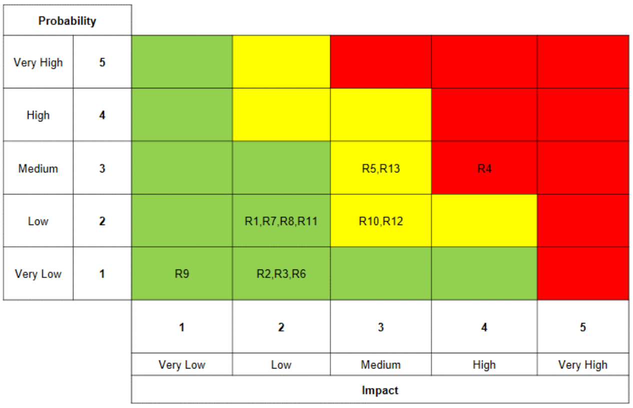


**Fig. 6.** Risk probability-impact matrix.

**Table 3.** Internal Variables and their relative importance.

| | | **Weight of WHAT'S** | | |
|---|---|---|---|---|
| W1 | Preserving the environment | 8 | 9 | 10 |
| W2 | Improvement of people´s health | 8 | 9 | 10 |
| W3 | Satisfy the need of costumers to generate energy | 6 | 7 | 8 |
| W4 | Having a competitive portfolio in the market | 7 | 8 | 9 |
| W5 | Profitability of the company | 7 | 8 | 9 |
| W6 | Alignment with the standards of the parent company | 6 | 7 | 8 |
| W7 | Use of adequate equipment and logistics for handling batteries | 4 | 5 | 6 |

However, it is essential to mention that all risks remained in the range between High and Very High, which means that the five risks must have high priority when establishing actions oriented towards mitigation or elimination by those involved.

## 4. Conclusions

Lead is an element recognized for its toxicity, whose handling carries many risks in its recycling process, including storage, transport, and manufacturing. According to the results, the most critical risks are related to human participation, precisely due to such toxicity. The application of the FQFD allows for prioritizing risks considering the strategic objectives of the processes associated with the reverse supply chain. By considering these objectives and the impacts that risks have on them, better actions can

**Table 4.** Weight of the How's.

| | Strategic objectives or "How's | Weight of How´s | | |
|---|---|---|---|---|
| H1 | Continuously improving processes | 45 | 59 | 76 |
| H2 | Safe working methods | 43 | 57 | 74 |
| H3 | Preserving the environment | 46 | 61 | 77 |
| H4 | Ensuring the quality, reliability and technology of machinery and materials | 44 | 58 | 74 |
| H5 | Customer satisfaction | 43 | 57 | 73 |
| H6 | Ensuring battery tightness | 43 | 57 | 73 |
| H7 | Generate added value to the services offered | 45 | 60 | 76 |
| H8 | Support people's personal and professional growth | 42 | 56 | 72 |

**Table 5.** Results of prioritization.

| N° | DESCRIPTION OF THE RISK | IPRF |
|---|---|---|
| | **Very High** | **478** |
| R13 | Poor knowledge about lead toxicity and its management | 462 |
| R10 | Release of fragments and lead dust at the recycling plant | 462 |
| R5 | Soil and environmental pollution from surrounding areas | 458 |
| R4 | Manual battery handling | 439 |
| R12 | Contaminated dust in the screening | 436 |
| | **High** | **375** |

be defined or targeted, achieving a more significant effect on the reverse supply chain's overall performance. From the results obtained, the mitigation actions should be geared towards training the staff involved in battery recovery activities to minimize harmful health effects.

Because lead is a highly polluting material, and its extraction and processing negatively affect the environment, recovery from it is significant to minimize such effects. However, if this process's risks are not considered, the benefits that can be obtained in the environment would be counteracted with the negative impact on people's health. This is one reason why prioritization and intervention of these risks is critical Future work could comprise the specific actions towards mitigating or eliminating these risks; other possible works could consider the effects in the environment using, for instance, systems dynamics models to evaluate the environmental impact in the long term.

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# The Unequal-Area Facility Layout Problem: A Review

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**Abstract.** The facility layout problem is one of the important and complex problems in operations management literature. When area requirements of departments are different, the problem is known as the unequal-area facility layout problem (UAFLP) and consists of locating a number of departments within a facility plan, in order to minimize the total material handling cost, which is the most addressed criteria for the facility layout problems. In this paper, a review for the UAFLP is presented as well as the explanation of how this kind of problem can be solved.

**Keywords:** Facility layout, unequal-area, material handling, solution techniques.

## 1 Introduction

The facility layout optimization is considered as an important and complex decision in operations management. The facility layout problem (FLP) consists of determining the location of the facilities (i.e. machines, workstations, departments, etc.) of a manufacturing or service company within a floor plan in order to optimize qualitative and/or quantitative criteria (Armour & Buffa, 1963; Drira et al., 2007; Meller & Gau, 1996). When facilities have unequal area requirements, that is, the dimensions of their widths and lengths are different, the problem is known as the unequal-area facility layout problem (UAFLP), and it is one of the most important problems in FLP literature (Armour & Buffa, 1963; Kulturel-Konak et al., 2004; Meller & Gau, 1996; Wong & Komarudin, 2010). The UAFLP was first presented by Armour & Buffa (1963) and considers a continuous arrangement of the facilities within a rectangular region subject to a) department and floor area requirements, b) department non-overlapping constraints, and c) department maximum aspect ratio constraints (Komarudin & Wong, 2010; Kulturel-Konak et al., 2004).

The solution of the UAFLP is a block layout which specifies the location and dimension of the departments (Jankovits et al., 2011; Kulturel-Konak & Konak, 2011a). The UAFLP is frequently addressed in the research literature, since its characteristics are similar to real-life layout problems (Balamurugan et al., 2006). In general, the facility layout optimization is known to have an impact on manufacturing costs, work-in-process inventory, lead times and productivity (Drira et al., 2007; García-Hernández et al., 2015). In order to achieve this impact, the UAFLP is usually optimized by minimizing the total material handling costs (MHC) of a layout alternative, which is considered as a major operational cost for an organization (Tompkins, 2010). However, other qualitative criteria, such as the closeness relationship between departments, has also been applied for optimizing the UAFLP (Aiello et al., 2013; García-Hernández et al., 2014; Ripon et al., 2011).

Due to the existence of non-linear area constraints, the UAFLP is recognized as a complex NP-hard class problem. For this reason, a wide variety of exact non-linear and relaxed linear programming models have been proposed for addressing the UAFLP (Armour & Buffa, 1963; Castillo et al., 2005; Meller et al., 2007; Meller & Gau, 1996; Sherali et al., 2003). In the same sense, a large amount of heuristic, metaheuristic, and even matheuristic algorithms have been presented for obtaining good solutions in short computational times for the problem (García-Hernández et al., 2019; Komarudin & Wong, 2010; Kulturel-Konak & Konak, 2011a; Paes et al., 2017; Palomo-Romero et al., 2017; Ulutas & Kulturel-Konak, 2012).

## 2 Background

As mentioned before, the FLP has been a widely addressed problem in operations management literature. A large amount of documents have been published regarding the different variants of the problem, as well as reviews about the proposed construction algorithms, metaheuristic approaches and mathematical formulations for the problem (see for example Kusiak & Heragu (1987), Drira et al. (2007), Singh & Sharma (2006), Meller & Gau (1996), Kundu & Dan (2012), Anjos & Vieira (2017), Hosseini-Nasab et al. (2018) and Kikolski & Ko (2018)).

In relation to the UAFLP, Drira et al. (2007) reviewed some metaheuristic approaches for solving the problem, while Kundu & Dan (2012) and Anjos & Vieira (2017) analyzed and described the different mathematical formulations that have been presented. Ever since its presentation by Armour & Buffa (1963), publications have been focused on solving the UAFLP via exact and heuristic procedures. Exact non-linear formulations for the problem were initially addressed, but due to computational intractability, linearization methods have been a very important issue for the problem. Montreuil (1991), Meller et al. (1998), Sherali et al. (2003) and Castillo & Westerlund (2005) have made contributions to improve the approximation methods for linearizing the non-linear area constraints.

Other very frequently approach has been the implementation of heuristic, metaheuristic and matheuristic procedures. In these approaches, the problem is represented by one of the following most common structures: flexible bay structure (FBS), slicing tree structure (STS) and shape-based block layout structure (SBL). FBS is known to be the easiest and most simple structure to implement, where departments are grouped and located within parallel bays with varying widths in the floor space

(Kulturel-Konak & Konak, 2011b). STS is a more complex structure that divides the facility horizontally and vertically in order to locate the departments (García-Hernández et al., 2020). Finally, SBL also considers bays with varying widths to locate fixed-shaped facilities (Lee & Lee, 2002).

## 3 The Unequal-Area Facility Layout Problem

The unequal-area facility layout problem (UAFLP) is an important and widely applied problem in both academia and industry (Chae & Regan, 2016; Kulturel-Konak et al., 2004; Meller & Gau, 1996; Wong & Komarudin, 2010). The continuous representation of the departments on the floor plan, as well as the consideration of unequal area requirements for the departments, brings this problem be more realistic for facility planners. In addition, the objective is to minimize MHC, which seeks to decrease the wastes related to transportation and unnecessary material movements inside the facility.

The UAFLP consists of locating a set of $n$ departments within a facility plan, while considering area ($a_i$) and aspect ratio ($\beta_i$) requirements for each department $i$. Also, for each department $i$, the coordinates of its centroids ($x_i, y_i$) and the dimensions of its width ($l_i^x$) and height ($l_i^y$) are determined. The distance between a pair of departments ($d_{ij}$) is computed according to the rectilinear distance norm, for this application, and the flow of materials ($f_{ij}$) is also considered for determining the MHC, as shown in equation (1). An exact mixed integer non-linear programming formulation for the UAFLP is presented below, adapted from (Kang & Chae, 2017).

*Notation and Parameters*

| | |
|---|---|
| $n$ | number of departments |
| $i, j$ | indexes for the departmetns, $i < j$ |
| $L^x, L^y$ | dimensions of the width and height of the facility, respectively |
| $a_i$ | area requirements for department $i$ |
| $\beta_i$ | maximum aspect ratio requirement for department $i, \beta\_i \geq 1$ |
| $f_{ij}$ | volume of material flow between departments $i$ and $j$ |

*Decision Variables*

| | |
|---|---|
| $d_{ij}$ | rectilinear distance between departments $i$ and $j$ |
| $l_i^x, l_i^y$ | dimensions of the width and height of department $i$, respectively |
| $c_i^x, c_i^y$ | coordinates of the centroid on the axis $x$ and $y$ for department $i$, respectively |
| $z_{ij}^x$ | 1, if department $i$ is located to the left of department $j$.<br>0, otherwise. |
| $z_{ij}^y$ | 1, if department $i$ is located lower than department $j$<br>0, otherwise. |

$$\text{Minimize MHC} = \sum_{i=1}^{n} \sum_{j=1, i \neq j}^{n} f_{ij} d_{ij}, \tag{1}$$

subject to:

$$d_{ij} = |c_i^x - c_j^x| + |c_i^y - c_j^y|, \forall\, i, j\ (i \neq j), \tag{2}$$

$$a_i = l_i^x * l_i^y, \forall\, i, \tag{3}$$

$$\sum_{i}^{n} a_i \leq L^x * L^y, \tag{4}$$

$$\frac{\max\{l_i^x, l_i^y\}}{\min\{l_i^x, l_i^y\}} \leq \beta_i, \tag{5}$$

$$\begin{aligned} c_i^x + \frac{l_i^x}{2} &\leq c_j^x - \frac{l_j^x}{2} + L^x(1 - z_{ij}^x), \forall\, i \neq j, \\ c_i^y + \frac{l_i^y}{2} &\leq c_j^y - \frac{l_j^y}{2} + L^y(1 - z_{ij}^y), \forall\, i \neq j, \end{aligned} \tag{6}$$

$$\begin{aligned} \frac{l_i^x}{2} \leq c_i^x \leq L^x - \frac{l_i^x}{2}, \forall\, i, \\ \frac{l_i^y}{2} \leq c_i^y \leq L^y - \frac{l_i^y}{2}, \forall\, i, \end{aligned} \tag{7}$$

$$z_{ij}^x + z_{ji}^x + z_{ij}^y + z_{ji}^y = 1, \forall\, i \neq j, \tag{8}$$

$$z_{ij}^x, z_{ij}^y \in \{0, 1\}, \forall\, i \neq j. \tag{9}$$

The mathematical model aims to minimize total MHC between departments, subject to the following sets of constraints:

- equation (2) defines the rectilinear distance norm between departments,
- constraint (3) ensures that the area requirements for each department are satisfied, being this constraint the one that increases the complexity of the problem due to its non-linear nature;
- constraint (4) ensures that the total area of the departments is within the dimensions of the floor space.

The aspect ratio constraint, which allows a maximum aspect ratio between the longest and shortest sides of each department, is established in (5). The set of constraints (6) and (7) prevent the departments from overlapping, and ensure that the departments are located within the floor plan. Finally, constraint (8) defines the relative location of each department, while constraint (9) establishes the binary conditions of the location variables.

## 4 Solution Procedure for the Unequal-Area Facility Layout Problem

The UAFLP is known to be a NP-class problem (Kulturel-Konak & Konak, 2013; Meller & Gau, 1996), which requires huge computational capacities to be solved to optimality for large instances. In the following sections, the description and application of a GA metaheuristic for solving the UAFLP for the case of the garment industry is presented. Once the problem has been appropriately represented, the selected heuristic or metaheuristic algorithm is applied. Some metaheuristic Genetic algorithms (GA) (García-Hernández et al., 2015; Kulturel-Konak & Konak, 2013; Lee et al., 2003; Liu & Meller, 2007), simulated annealing (SA) (Allahyari & Azab, 2018; Bozer & Wang, 2012; Salas-Morera et al., 2020; Turgay, 2018) and ant colony optimization/ant systems (ACO/AS) (Komarudin & Wong, 2012; Kulturel-Konak & Konak, 2011a; J. Liu & Liu, 2019; Wong & Komarudin, 2010), which are found to be the most common metaheuristics for solving the UAFLP in the recent literature.

In relation to the application of the UAFLP to real-life industrial scenarios, literature is scarce. The cases of the ovine slaughterhouse (Salas-Morera et al., 1996), the carton pack recycling and the chopped plastic plants (García-Hernández et al., 2013) have been addressed and also considered as data instances for the problem. Other real-life applications of the UAFLP include the manufacturing of metalworking tools (Allahyari & Azab, 2018), the manufacturing of auto parts (Balamurugan et al., 2008) and the production of diesel motors ( Liu et al., 2018).

When determining the best facility layout alternative, most of the publications have focused on material handling costs (MHC). MHC is a distance-based metric, where the distance is measured according to one of the following distance norms: rectilinear (Manhattan) distance, Euclidean distance, squared Euclidean distance or Chebyshev distance (Gonçalves & Resende, 2015; Xie et al., 2018). Rectilinear distance norm, which is computed as the sum of the horizontal and vertical distance between two points, is frequently considered by authors because it represents real-world layout problems (Gonçalves & Resende, 2015).

## 5 Conclusions

This article presented a review for the unequal-area facility layout problem, higthligthing its importance and presenting the mathematical formulation of the problem, from which it is possible to identify a high number of variables, parameters and restrictions that makes its solution a complex process. For that reason, it was found in the literatures that several metaheuristic procedures have been developed for the problem solution, as it is the case of genetic algorithms for evolution-based and ant colony for trajectory-based techniques.

As future research work, the model can be applied in many industrial sectors that require layout design for improving their operations, as many small factories in latin America. For that, it is required the development of solution techniques for solving the model, from which Genetic algorithms are chosen due to their easy application and good results in this kind of problems.

Other future research line is to consider more characteristics of the problem, such as dynamic and stochastic environments may also be considered to close the model to the real-world industrial case, as well as the joint optimization of the unequal-area facility layout with other operations management decisions, such as production planning and scheduling.

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# Decision Support System: A Bibliometric Review

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**Abstract.** This paper presents a bibliometric review regarding the evolution of Decision Support Systems (DSS). A search was performed in the Scopus and Web of Science databases with keywords related to the topic from 1977 to 2021 to identify full research articles, book chapters, books, and papers in international conferences and congresses. A total of 5,018 documents were identified for analysis in the VOSviewer® software to identify the trend of publications, the countries with prominent research groups, the institutions with the most publications, collaborations between nations, among others. Findings indicate that DSS is a research area with exponential growth and academic and industrial interest. The leading journals that publish these topics are Decision Support Systems, Lecture Notes in Computer Sciences, and Expert Systems with Applications. The main publishing countries are the United States of America, China, United Kingdom, Italy, Australia, and India. The application areas of DSS are Medicine, Computer Science, Engineering, Mathematics, and Nursing. The principal authors are Haynes, R.B. and Gerrdine, D., and Abrent, A. At the same time, the institutions that receive the most citations are the University of Minnesota and the University of Cincinnati, both in the USA, and McMaster University in Canada.

**Keywords:** Decision support system, bibliometric review, trends.

## 1 Introduction

Humans always are making decisions. A decision is the determination to act in a situation that presents several alternatives [1]. From the above, it can be concluded that there must be a decision-maker and alternatives to meet an objective (maximized, minimized, or a nominal value). Often, some criteria and attributes must be analyzed, so it is common to observe multicriteria and multi-attribute decision-making [2].

Even with the above, one decision-maker may classify a decision as good; however, another may classify it as bad, and this is due to their own experience. Decisions may be rational, satisfactory, organizational procedure, and political. However, all decision-making process consists of 5 stages: intelligence, design, selection, implementation,

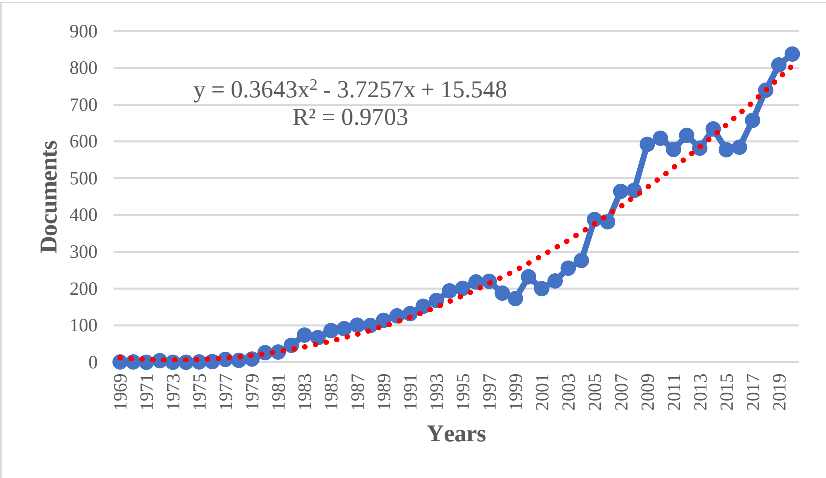


**Fig. 1.** Publications by year with the title "decision support system" or "Decision Support System".

and review [3]. According to the method used in a decision-making process, these are classified into programmed and non-programmed, depending on if the problem is structurally well defined. Also, it can be a routinary if the relationships can be predicted, and anyone can execute them; however, it can be complex if relationships are not defined. This is where decision support systems have been developed [4]. A decision support system is a way of modeling data and making quality decisions [5].

A DSS is a computer application that, together with a decision-maker, filters the information and evaluates the alternatives [6]. DSS can be passive or active if it collects and processes the data, is cooperative if it contains the data, analyzes it, and proposes a solution. Finally, driven DSS is when statistical tools, simulations, or financial models offer a solution. Fallon, *et al.* [7] are the first to refer to DSS in the health sector, but two years later, Vienot [8] began to define the main DSS in this sector; however, four years later, he presented a DSS for use in risk analysis by banks and Hansen, *et al.* [9] are the first to report a DSS with an interfaced computer program.

A search in Scopus indicates that there are a total of 13,796 papers with the title the word (TITLE ("decision support system") OR TITLE ("Decision support system") OR TITLE ("Decision Support System") OR TITLE ("DECISION SUPPORT SYSTEMS")), indicating academic interest (consultation conducted on September 08, 2021). Figure 1 illustrates the distribution of these 13,796 published papers included in Scopus, where 563 documents from 2021 and 8 from 2022 have already been omitted. The red dotted line indicates a quadratic trend and can be observed that from 1983 onwards, the DSS began to boom.

The applications of DSS are multidisciplinary, and Figure 2 illustrates the top ten academic areas that develop DSS. The main areas refer to computational sciences, engineering, medicine, and social sciences. There are 13,237 documents in English, 260 in Chinese, 60 in German, 41 in French, 37 in Portuguese, 34 in Spanish, among others. The documents refer to 7,149 scientific articles, 5,548 conference papers, 401

**Table 1.** Main areas of literature reviews.

| Review area | Number | References |
|---|---|---|
| Medicine | 178 | [10,13] |
| Computer Science | 60 | [12,13] |
| Engineering | 50 | [14,15] |
| Agricultural and Biological Sciences | 48 | [16,17] |
| Environmental Science | 47 | [18,19] |
| Business, Management and Accounting | 33 | [20,21] |
| Nursing | 31 | [22,23] |

book chapters, 397 reviews, 88 editorial releases, 45 errata, 41 notes, 38 letters to the editor, 33 books, 19 small surveys, among others. Nowadays, there are reviews on DSS, and Table 1 shows a summary. Observe that a large percentage of them are focused on medicine and computer science. In medicine, Harada, *et al.* [10] present a literature review focused on DSSs used by physicians in early diagnosis to decrease risks of future diseases, while Abdellatif, *et al.* [11] report a review of DSSs applied to nurses who support older people in their own homes, allowing them to streamline decision making. Likewise, Aktürk [12] reports a bibliometric review of DSS used in clinical analysis.

The number of specialized reviews reported about DSS is justified, given the number of existing papers in each research area. However, some of these reviews almost always include theoretical documents that lack real applications, even if they are thematic. Sometimes, they are improvements made to another DSS, focusing only on proposing a new modification. Given the above situation, revisions are required to address DSS applied to some sectors, not only theoretical concepts that provide new proposals.

Given this situation and intending to contribute to this area of research and take advantage of specialized software to carry out this activity, the objective of this chapter is to present a bibliometric review of DSS applied to any sector. This work will allow DSS scholars to identify the leading research groups, the universities that publish, the most cited authors, and the journals that focus on this topic. After this brief introduction, section two presents the methodology used to achieve the proposed objective, section three presents the results found, and finally, the conclusions are offered.

# 2 Methodology

## 2.1 PRISMA Method

To identify the articles to be analyzed, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology was used [24] since it has been used in similar studies in the health area by Li, *et al.* [25]. The identification of the documents is performed in the Scopus and Web of Science (WOS) databases, although Lens and Dimensions are used alternatively. The search equation was as follows: (TITLE ("decision support system") OR TITLE ("Decision support system") AND TITLE-ABS-KEY ("decision making") AND TITLE-ABS-KEY ("decision-making"))

AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "ch")) AND (LIMIT-TO (LANGUAGE, "English")). The above indicates that only documents containing the word "decision support system," or "Decision support systems," or "Decision Support System" in the title are considered.

However, given that many DSS focused on computer systems, it was requested that the documents also contain the word "decision making" or "decision-making" in the abstract, which guaranteed their application. However, the following inclusion criteria were established: The search equation was as follows:

1. Papers must be final and not in print.
2. Only research articles, conference papers, and chapters are included to guarantee a scientific evaluation of them.
3. Finally, all papers must be written in English.

### 2.2 Analysis with VOSviewer

VOSviewer® 1.6.17 software is used for the analysis of the 779 documents that are identified by the PRISMA methodology, as it has been used in DSS applied to supply chain [21] and DSS in sustainable logistics [26]. The primary analyses focus on the following:

1. The trend of publications per year of applied DSS.
2. Authors, institutions, and countries that generate more scientific production in applied DSS.
3. Main keywords used by authors and publishers when indexing applied SSD papers.
4. Most cited articles, journals, authors, organizations, and countries in applied SSD.

## 3 Results

### 3.1 General Data of the DSS Applied

A total of 4,234 documents were identified in the Scopus and WOS databases, but also 1,385 in Dimensions and Lens. The results of both searches were downloaded in RIS extension to be read in Endnote 20® software, which made it possible to identify a total of 421 duplicate documents and obtain 5,198.

However, it has been established as an inclusion rule that all documents must be full text, which allowed the elimination of 18 more documents, leaving 5,180. In addition, it was established that only research articles, conference articles, book chapters, and books, written in English and published and not in press, are analyzed. This procedure made it possible to eliminate 162 more documents, leaving 5,018 documents to be analyzed. Figure 2illustrates the PRISMA method graphically, indicating the corresponding quantities in each of the stages.

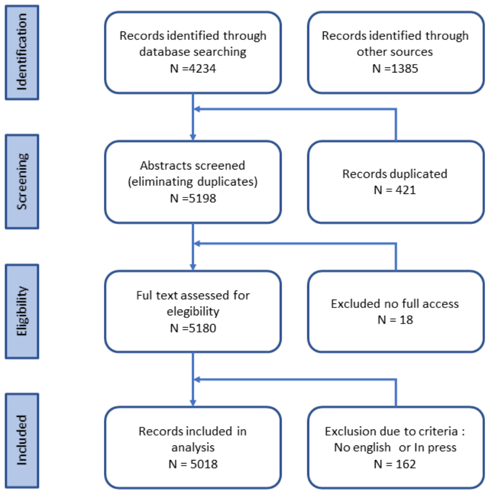


**Fig. 2.** Methodology for select documents.

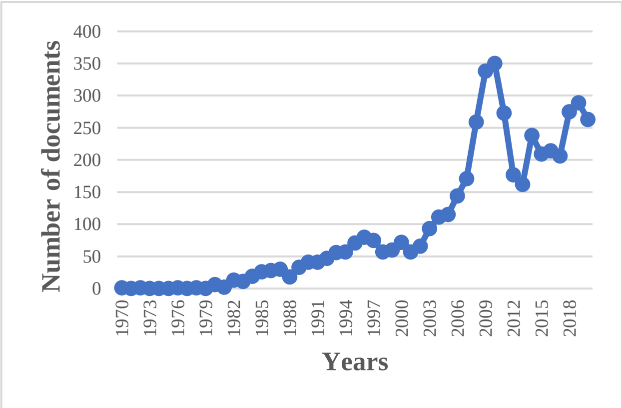


**Fig. 3.** Papers published.

Figure 3 shows the annual production that has existed about DSS applied up to 2020 since, in this case, 152 publications that already exist in 2021 and three in 2022 have not been included. In general, it is observed that it was from 1988 when the DSS began to have their peak, having their highest value in 2010 with 350 publications, and from that date, there was a decline until 2013, reaching only 162 publications in the same year. However, there is again an increase in the number of publications per year from that year onwards, although it is far from reaching the paper's production of a decade ago.

An essential aspect of the DSS is to know the entities or sources of funding since it is a metric of the levels of importance given to this topic, and Figure 4 illustrates the top ten. It is essential to mention two aspects. The first is that there are three offices

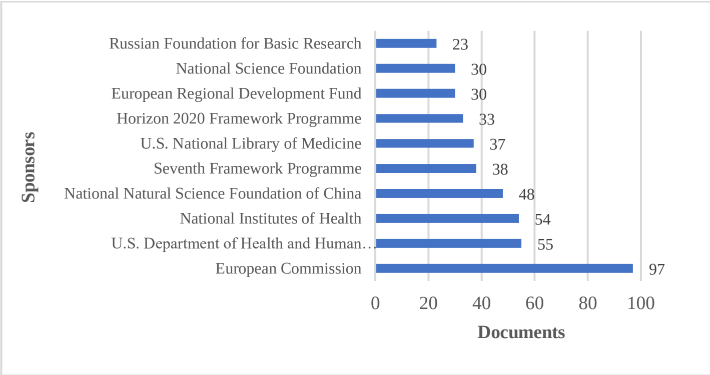


**Fig. 4.** Main sponsors in DSS applied.

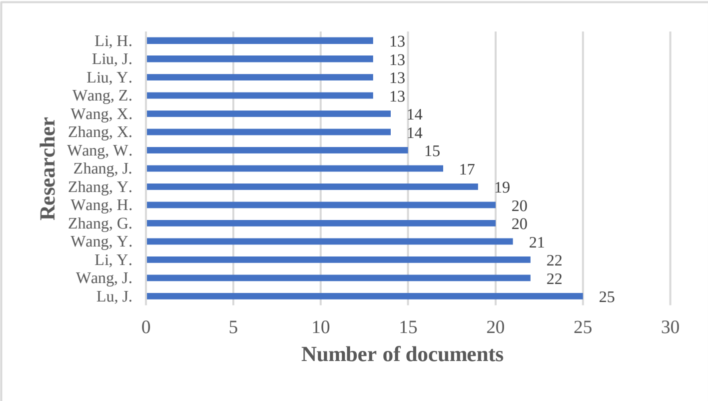


**Fig. 5.** Most productive authors.

focused on health sciences, and the second is that there are two European offices, which indicates that geographically in Europe, much emphasis is being given to this type of research applied to DSS and that health is a science in which it has been very well accepted. On this occasion, it can be seen that the European Commission is one of the primary sources of funding, sponsoring 97 investigations. At the same time, the U.S. Department of Health and Human Services, which is an office focused on health, is in second place with 55 investigations.

## 3.2 Authors, Organizations, and Countries that Publish the Most

Figure 5 illustrates the 15 most productive authors in the field of applied DSS. It can be seen that the most productive author is Lu, who starts by presenting a paper at a conference [27], and his most recent article is in 2018 [28]. The next author is Wang, J. started his production in 2004 [29], and his most recent publication was in the year

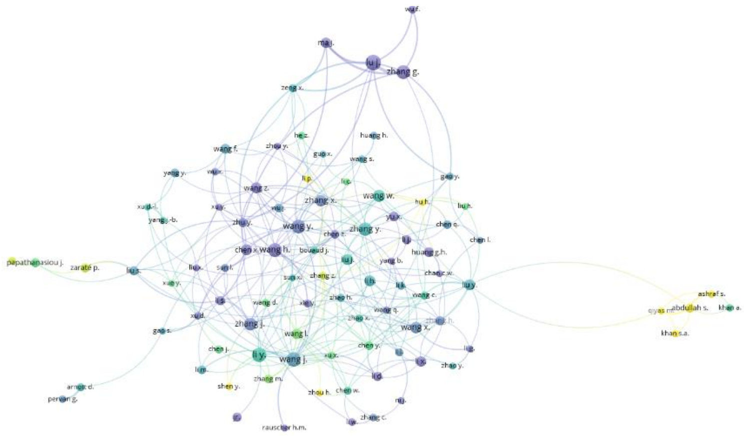

**Fig. 6.** Relationships and consolidation of authors.

2021 [30]; being more productive concerning time refers to a co-authorship with the first-place author.

Figure 6 illustrates a diagram of relationships among the most active authors. Ten clusters were identified. In this case, the size of the circles is associated with the number of published articles, while the color is related to the years of consolidation. Among the most consolidated authors are Wang, Y., Wang, H., Zhang, X. The green colors are authors in consolidation, such as Li, Y., Li, M., Zhang, Y., among others. Finally, the authors beginning their scientific production process are Zaraté, P., Zhang, Z., Hu, H., among others.

Table 2 illustrates the leading institutions and research institutes that have published the most on the topic of applied DSS. In this case, it is observed that the IEEE is the organization that has published the most with 10 in total; however, it is not the one with the most citations. It is essential to mention that the IEEE appears without an associated country, given that it has different research centers around the world. The second place is occupied by the Algoritmi Centre of Portugal and the Systems Research Institute of Poland, with five publications each. They have more citations than the works reported by the IEE. Please note that two institutions from Portugal appear in Table 2, which indicates the importance of DSS research for that country.

Although a total of 9,579 different author affiliations have been identified, many of these institutions have only one document, and it has often not been cited. Figure 7 illustrates the relationships between the different institutions and clearly shows that the IEEE is the institution that has published the most and that has academic relationships with many other institutions.

In this case, the consolidated institutions researching DSS are the Advanced Technology R&D Center of the Mitsubishi Electric Corporation of Japan. Although a total of 9,579 different author affiliations have been identified, many of these institutions have only one document, and it has often not been cited. However, there is a large grouping of institutions, so Figure 7 illustrates an approach to this group of

**Table 2.** Institutes and research centers in DSS.

| Organization | Documents | Citations |
|---|---|---|
| IEEE | 10 | 19 |
| Algoritmi Centre, University of Minho, Portugal | 5 | 36 |
| Systems Research Institute, Polish Academy of Sciences, Poland | 5 | 100 |
| Department of Industrial Engineering, Stellenbosch University, South Africa | 4 | 1 |
| Department of Information Systems, Stmik Pringsewu, Indonesia | 4 | 24 |
| GECAD –Institute of Engineering, Polytechnic of Porto, Portugal | 4 | 34 |
| Institute of Informatics and Computing Energy, Universiti Tenaga Nasional, Malaysia | 4 | 42 |
| University of Southampton, United Kingdom | 4 | 88 |
| Business Information Systems, University College Cork, Ireland | 3 | 18 |
| Delft University of Technology, Netherlands | 3 | 21 |
| James Madison University, United States of America | 3 | 14 |
| PBS & J, United States of America | 3 | 1 |

**Table 3.** Production by country.

| Country | Documents | Citations |
|---|---|---|
| United States of America | 1043 | 19233 |
| China | 596 | 3631 |
| United Kingdom | 337 | 5701 |
| Italy | 223 | 3275 |
| Australia | 220 | 3511 |
| India | 209 | 1473 |
| Germany | 206 | 2749 |
| Canada | 189 | 4612 |
| Spain | 177 | 3620 |
| France | 159 | 1706 |
| Netherlands | 152 | 2844 |
| Indonesia | 140 | 393 |
| Greece | 127 | 2302 |
| Russian Federation | 121 | 419 |
| Taiwan | 118 | 2371 |

institutions, where it can be seen that there are many more, all of which are established in Japan.

Table 3 shows the production of documents by country and their citations. It can be seen that the USA is the country that has published the most papers, with a total of 1,043, and of this group, it is the most cited. China's second place is occupied with 596 documents and 3,631 citations, while the United Kingdom occupies third place with 337, but with 5,701 citations, a higher value than that of China.

From this list, the United States of America and Canada represent the Americas. In contrast, countries such as the United Kingdom, Italy, Germany, Spain, France, Holland, and Greece represent Europe, and Asia is represented by China, India, Russia, and Taiwan. Unfortunately, there are no Latin American countries in this list of countries with the most publications.

Figure 7 illustrates the top fifteen journals that publish on DSS. However, there is a list of 843 sources (journals or conferences), of which only 153 have published at least

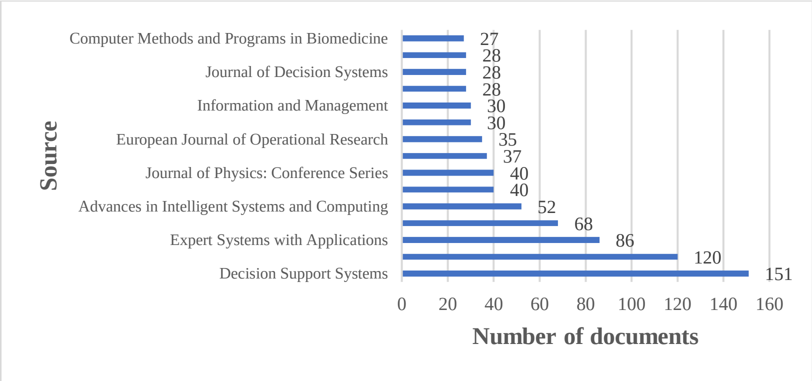


**Fig. 7.** Papers published on DSS by journal.

**Table 4.** Most used keywords.

| **Keyword** | **Occurrences** |
|---|---|
| decision support system | 1696 |
| decision making | 287 |
| decision support | 180 |
| data mining | 87 |
| gis | 79 |
| artificial intelligence | 71 |
| clinical decision support system | 71 |
| ontology | 71 |
| fuzzy logic | 70 |
| decision support system (DSS) | 69 |
| clinical decision support systems | 57 |
| optimization | 56 |
| simulation | 54 |
| multicriteria decision making | 50 |
| data warehouse | 48 |

five papers. It is observed that, given the level of importance of DSS, there is a journal specialized in this topic called Decision Support Systems that has 151 publications and ranks first in publications, followed by Lecture Notes in Computer Sciences that has 120 and Expert Systems with Applications that has 86.

Other journals are Computers and Industrial Engineering, Information and Management, and Decision Sciences, Lecture Notes in Computer Science, Expert Systems with Applications and Computers, and Electronics in Agriculture. Table 4 illustrates the main keywords used by the authors. It can be seen that the "decision support system" is the most used with 1696 occurrences. The second place is occupied by decision-making with 287 occurrences. A total of 9,721 keywords and some associated industrial sectors and techniques appears, such as AHP, promethee, heuristics, among others.

It is not precisely the Journals that publish the most that are the most cited. Figure 8 illustrates the most cited sources, where the journal Decision Support Systems

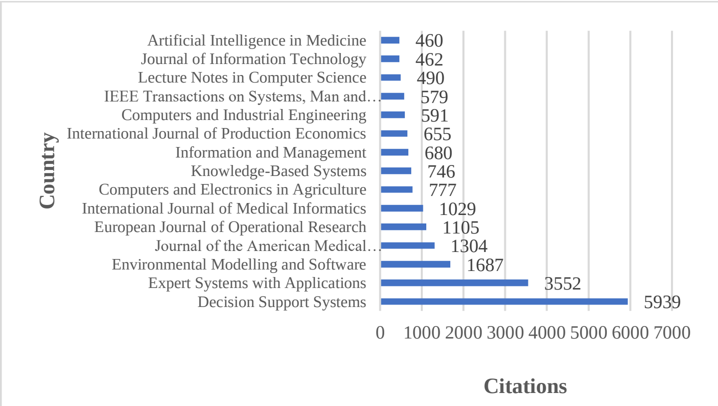


**Fig. 8.** Most cited sources per country.

(Elsevier) occupies the first place in citations, with 5,939 for its 1,351 published documents. On this occasion, it is consistent with the journal that has published the most on DSS. However, the journal Expert Systems with Applications (Elsevier) is in second place with 3,552 citations to its 86 papers, displacing Lecture Notes in Computer Science (Springer).

## 4 Conclusions

From the analysis of 5,018 published papers on DSS applications, the following conclusions can be drawn:

- The application of DSS has exponential growth.
- The United States of America is the country that has generated the most documents and has received the most citations.
- The main applications of DSS are in Computer Science, Engineering, Decision Science, and Medicine.
- The main sponsor or source of funding for this line of research that generates DSS is the European Commission.
- The most cited institutions are the University of Minnesota and the University of Cincinnati.
- The most cited organizations are the IEEE, the Algoritmi Centre in Portugal, and the Systems Research Institute in Poland.
- The journals that publish the most on DSS topic are Decision Support Systems and Lecture Notes in Computer Science.
- The three most used keywords in papers related to DSS are decision support system, decision making, and decision support.
- The most cited authors are Haynes R.B. and DeSanctis and Gallupe.

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# Design of a Blockchain Network Construction Methodology for Maintaining Patient Records based on Analysis and Modeling of Components with Standard ISO/IEC 29110 and UML for Hyperledger Iroha

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**Abstract.** The use of blockchain technology is one way to make data more trustworthy in the health domain; blockchain is essentially a distributed database of digital transaction or event logs that are executed and shared between participating parties. Developing a secure and effective system has been suggested to strengthen the health sector supply chain and enable a combination of cost reduction and increased accessibility to information. The approach of this paper is a blockchain network construction methodology to improve health data management and structure a system using the potential of blockchain technology in multiple ways to hold and control access to health data. A mixed-methods methodology was applied: a structured literature search on the topic was conducted in February–May 2021, document review, survey, focus group workshops, observation, and brainstorming. Technology can be part of the development solution, a scenario that focuses on obtaining the most excellent certainty for the correct treatment of the patient; the healthcare plans complex scenarios be seen in the light of this new blockchain technology.

**Keywords:** Hyperledger, blockchain, iroha, consensus, secure storage.

## 1 Introduction

The storage of data year after year has become a challenge in information technology; this process does not require only storage but the analysis, reading, and the possibility that the information generates an economic benefit for the company [1]. A current tool that can benefit resource management in hospitals is blockchain technology, considered as an emerging technology; it is a term born in the world of information and communication technologies that have become a general use term, used in various areas of knowledge, although mainly in economics [2]. The study attempts to answer the following questions:

a) Is it helpful to have the complete medical file of a patient available online with the certainty that the registered operations have not been altered or modified?
b) How could blockchain technology, in conjunction with electronic data capture systems, be applied to automatically aggregate, replicate, and distribute clinical data among medical personnel?
c) What are the relevant variables considered by physicians to better perform patient care and diagnosis?

Blockchain is a distributed database of digital transactions or event logs executed and shared between the participating parties. Each transaction in the blockchain is verified by the consensus of most of the participants in the system, and when added, the information remains until it is required or requested by an agent, client or staff, waiting in advance for authorization [3]. Transactions are grouped into blocks with a timestamp that reflects the instant or time that transaction is created, and these blocks are linked in chronological order. Applying blockchain technology to health data would imply using its principal characteristics from the point of view of information management, which are:

a) First, the data is stored in a chain of immutable transactions that anyone can read.
b) Second, blockchain is implemented in a decentralized network of computer nodes, making it robust against failure and attack.
c) Third, the metadata describing each transaction is available to everyone in the system [4].

## 2 Literature Review

This paper focuses on the architectural design for blockchain-oriented applications and proposes a construction methodology to improve the performance-based in UML (Unified Modeling Language). Arango et al. [5] consider that the systems development process involves a successive construction of models; that initially describe the application domain until reaching the solutions models, including technical aspects of the chosen implementation platform. For Fuentes et al. [6], a model describes a system in a well-defined language. A well-defined language has precise syntax and semantics that can be interpreted and manipulated by a computer.

Rumbaugh et al. [7] describe models as the entity that allows us to “grasp and exhaustively list the requirements and knowledge domain of a system so that all those involved can understand and agree with them” (p. 13). They also define UML as a visual modeling language used to specify, visualize, build, and document artifacts of a software system (p. 15). The UML is also the language proposed by the OMG (Object Management Group), an international organization whose objective is to standardize information technologies to the specification of computer systems [8].

### 2.1 Blockchain

The concept and the blockchain technology were created in 2009, and it is a technology that allows data transfer in a completely secure way thanks to sophisticated encryption. Essentially, a blockchain network is just a database that allows new records to be read and written. This technology represents the most critical change in databases since they were developed almost 50 years ago.

Blockchain is a person-to-person public accounting that is maintained through a distributed network of computers, and that does not require any central authority or third parties to act as intermediaries [9].

The basic idea behind blockchain technology is that it allows system actors (called nodes) to make digital transactions of assets using a peer-to-peer (p2p) network that stores these transactions in a distributed way over the network.

The assets' owners and the transactions involved in the change of ownership are recorded in the account book (ledger) through public cryptographic keys and digital signatures [2].

### 2.2 Blockchain Types

In blockchains, we can differentiate three main types of blockchain: private, public, and consortium [10]. In the private blockchain, only specific parties can read information and perform transactions. In the public blockchain, any user can join the network and access its information; the consortium blockchain is a mix of private and public.

### 2.3 Consensus Mechanisms

According to Islam et al. [11], a prominent feature of blockchain is the intervention of miners or nodes that validate and group transactions in blocks generated in the chain; this is called a consensus mechanism. Also, the consensus mechanism establishes which user in the blockchain will append the transactions to the chain as a new block.

The most common consensus algorithms in blockchain systems are proof of work, stake, and authority [12]. Consensus protocols allow transactions to be made by blockchain without relying on a third party. Selecting and implementing the correct consensus protocol is one of the most important decisions to be made at the beginning of a blockchain project.

## 3 Preliminaries

For the choice of the blockchain platform, the search was limited to those that have possibilities to a license with free software that allows you to work directly on the source code and documentation and are in a stable state of development. From this selection, we got the candidates named Hyperledger Iroha and Ethereum.

### 3.1 Blockchain Platform Chosen

The chosen platform is Hyperledger Iroha; what is Hyperledger? Hyperledger is an open-source project (open source) that was introduced in 2015 by the Linux Foundation for the development of platforms to create private blockchains with tools and programming code for the industry and the community in general; the Linux Foundation created in 2007, is a non-profit consortium dedicated to promoting the use and growth of the operating system for GNU / Linux computer systems and aims to increase its use in education, industry, and government, as well as adaptation and standardization in hardware and software components for this operating system. Sukhwani et al. [13] mention that one of the innovative characteristics of the Hyperledger platform is the consensus mechanism used to validate transactions and create blocks, this protocol is PBFT, and that transactions are controlled by a program code that provides the ability to write and design the applications that interact with the network. Hyperledger Iroha has the option of working both on a private network in permissionless, using thousands of nodes that are part of the Hyperledger Iroha network at the level global.

Additionally, Hyperledger Iroha has a creation time in which bugs found have been corrected, cases of use have been created in production, and more documentation is available to develop applications at an industrial level. Cachin et al. [14] and Valenta et al. [15] consider it a solution for constructing private-type platforms. Dhillon et al. [16] consider that the Hyperledger Iroha platform is designed as a development framework to include mobile device applications in large blockchain projects, as it integrates client libraries for application development on Android and iOS. The design of this platform also includes a domain approach, which allows a comprehensive development of set theory and set algebra and a high-performance, high-grade, fault-tolerant Byzantine consensus algorithm called YAC (Yet Another Consensus).

## 4 Proposed Scheme

The initial step is to identify the participants or users that interact with an application. First, a comprehensive evaluation is performed to identify actors and processes. These are the defined actors and processes:

- Actors (doctors, nurses, paramedics, administrative staff, relatives).
- Processes (information query, query data record, vital signs data record, right-of-way data records, family data record).

**Entity model.** The stakeholders in the proposed system can be divided into five groups: patients, patient family, medical staff (physician, caregivers, nurses), medical and administration/management.

**Data model.** The hospital blockchain links all parties related to hospital service into a whole network structure. The related transactions between parties are recorded and stored in the blockchain. All participants share the whole process information.

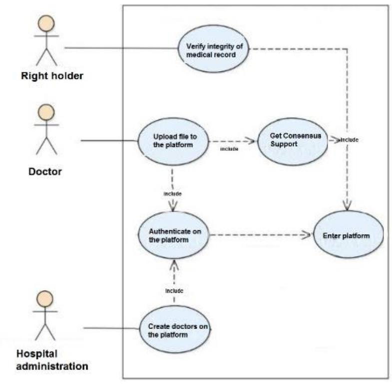


**Fig. 1.** Use case diagram.

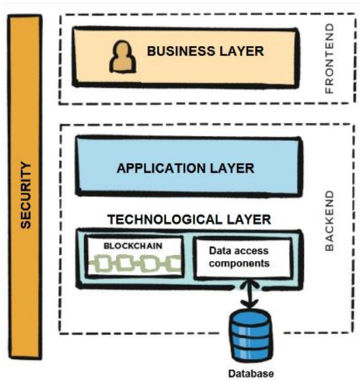


**Fig. 2.** Architecture.

**Use case model.** Diaz et al. [17] define the use case model as the model that contains the agents or actors that can interact with the system, where this interaction is shown in the use case form. In this activity, the elements of the use case in the patient care unit and the medical history management processes are identified, and the functions within the system and their relationship with the actors are reflected, as shown in figure 1.

**Architecture.** The proposed architecture consists of the following layers: business, application, and technology and aims to store medical history data. Figure 2 depicts the architecture of the model.

– Business layer: it is where all the logic of the business network is.
– Application layer: the connection layer contains the necessary infrastructure to receive information from the business and technological layers in real-time.
– Technological layer: this layer is the blockchain operating machine.

The components are explained in the following:

– Transaction Gateway: The transaction gateway is a connection component that will coordinate the various components that work together to discover and connect with the blockchain endpoint.

- Request Receiver: It is an upfront server that receives the HTTP requests.
- Communication Interface.
- Blockchain Engine: Hyperledger Iroha that it is one of the critical components.
- Functional Interface.

# 5 System Implementation

This section concerns the implementation and simulation of the blockchain-backed application. The Agile Unified Process (AUP) methodology will be followed, characterized by being directed to use case, focused on architecture, iterative and incremental. This application will assist stakeholders in performing tasks related to the issuance and validation of electronic health records. More specifically:

- Hospital institution.
- Patients.
- Medical Staff.

## 5.1 ISO / IEC 29110

The ISO / IEC 29110 standard is taken as a reference for developing the architecture because it is a compliance standard that helps ensure and increase the quality of the software product, strengthening the production process and understanding that a product is strongly influenced by the process that develops it. ISO / IEC 29110 contains two approaches:

- Management process.
- Software implementation.

## 5.2 Tools

The tools and accessories to be used for the development of the architecture are planned considering that the blockchain architecture is based on resources, where a resource is the abstraction of anything that can be conceptualized, as follows:

- Physical structure. As a hardware tool for the proposed system, a computer with Intel Core i5-8500 @ 2.00Ghz CPU, 8 GB of RAM, was used.
- Operating system. Ubuntu Linux (16.04.1 LTS) was installed for the operating system.
- Blockchain operating platform. Hyperledger Iroha.

### 5.3 Application Functionality

In this section, the installation, configuration, and startup of the technological layer is carried out, which is done from an Ubuntu terminal console and with the CLI of the blockchain platform (Command-line Interface), which is the communication path of the engine (machine) or main engine of blockchain work.

### 5.4 Installation

As the first step for the installation is the creation of the network.

- sudo docker network create Iroha-network

A workspace is set up.

- sudo docker volume create block store

The latest version of the engine is obtained and installed:

- sudo apt-get install git git clone -b develop https://github.com/hyperledger/iroha–depth = 1

### 5.5 Initialization

The platform is entered, and the execution begins, with the instructions:

- docker exec -it Iroha / bin/bash

### 5.6 Access

The controls are accessed to perform operations on the platform and to be able to enter instructions from the platform's CLI.

- Iroha -cli -account name admin@test.

Furthermore, we are shown the menu of operations.

- New transaction (tx).
- New query (qry).
- New transaction status request (st).

## 6 Conclusion and Future Work

This paper proposes a blockchain solution for managing data privacy, integrity, and process workflow for electronic health records. It also proposes a structure and a methodology for the construction of blockchain architecture. It is intended to expand the study using a cloud service such as AWS or IBM Blockchain to evaluate the proposed methodology in a production environment attached to a patient care unit.

Numerical analysis is also required to study the impact of hardware components, such as memory allocation, disk type and speed, network speed, and CPU. In addition, it is planned to investigate the impact of the proposed methodology on other new private blockchain platforms.

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# System Dynamics Application as a Tool to Evaluate Soil Improvement Strategies in Colombia's Sugarcane Cultivation

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**Abstract.** Sugarcane cultivation is one of the main crops in Valle del Cauca, Colombia. However, intensive agricultural production leads to soil depletion (which in the long run can seriously affect production) and therefore the economic development of the region and the country. In this study, it was proposed to evaluate through the system dynamics methodology, the possible long-term impacts that this crop could generate in the Valle del Cauca's soils. The simulation's model was applied using Vensim DSS software and it explored soil recovery scenarios using compost, which is produced from sugarcane residues composting (cachaça and bagasse). It was evident that the utilization of this by-product can represent an important contribution in the soil's loss and degradation reduction, plus economic and environmental benefits.

**Keywords:** Systems dynamics, land use, sugarcane.

## 1 Introduction

Over the past 50 years, agricultural technology advances and increased demand due to population's growth, have raised the soil's pressure. In many countries, intensive agricultural production has led to soil depletion, threatening the productivity of soils and the ability to meet the needs of future generations [1]. Colombian's agriculture is diversified, and traditional crops continue to occupy the largest proportion of the sowed area, highlighting those used as a raw material in the production of Colombian's most consumed foods.

This is the case of sugarcane, which has approximately sown 352,786 for 2019, (from this amount, 200,499 belong to the Valle del Cauca's department) [2, 3]. For this reason, it is necessary to conduct studies that contribute to an adequate management in the producer's side of the supply chain to identify and establish improvements in the production processes, and even more so in developing countries [4, 5].

The excessive use of commercial fertilizers has contributed to reduce the organic matter content (OMC) and different physicochemical soil's properties, resulting in its quality's decrease, acidification, and contamination. [6, 7].

Based on the problems caused by commercial fertilizers, organic compost use has led to a growing worldwide interest in the utilization of organic materials [8, 9], as it has been proved that these can increase soil's fertility and improve physical, chemical and biological properties [10] being a safer and more effective alternative for nutrient recovery [10, 11] and leading to a commercial fertilizer's usage reduction in regard to crop production [12].

An alternative to organic amendment is cultivation and processing by-products that come from sugarcane, such as cachaça and cane bagasse [13, 14]. Due to its high impact in the country, and even more in the Valle del Cauca's department (where there is a suitable cropping area of approximately 400,618) [15], this study assessed the applicability of the system's methodology dynamic, which is a modelling approach based on systemic thinking and the usage of feedback and delays information-based perspective.

This can be used to understand the dynamics of complex behavior on physical, biological, and social systems [16, 17]. In this study, the impact of applying compost (which results from cachaça's and cane bagasse's composting) over the cultivation of sugarcane, was evaluated over a period of 40 years using tools from system dynamics.

## 2 Methodology

The study was applied to the context of sugarcane cultivation in Valle del Cauca's department, Colombia. A diagram of Influences was drawn up and based on this a Forrester diagram was proposed to design two hypothetical scenarios for a period of 40 years. From 2001 to 2041, the scenarios have the following characteristics:

**Scenario 1** - Sugarcane cultivation with compost application: The compost application rate varies according to the type of soil, crop, and season. The World Health Organization (WHO) states that 100-300 Ton/Ha of compost is usually required per year [18].

This study assumed a requirement of 300 Ton/Ha compost from the cachaça's and bagasse's composting by-products, whose processing time is in the order of 90 days [14, 19]. In addition, a percentage of soil loss due to compaction was considered.

This is the most evident factor in the sugarcane production process due to the agricultural work generated by the agricultural machinery [20], which was 1% [21, 22].

**Scenario 2 -** Sugar cane cultivation without compost application: it is evaluated without the use of compost. In this case, a soil degradation rate of 0.004 is proposed [23, 24]. In both cases, it is assumed that the productions reported by the different sugarcane entities are based on traditional fertilization, which is made of chemical fertilizers.

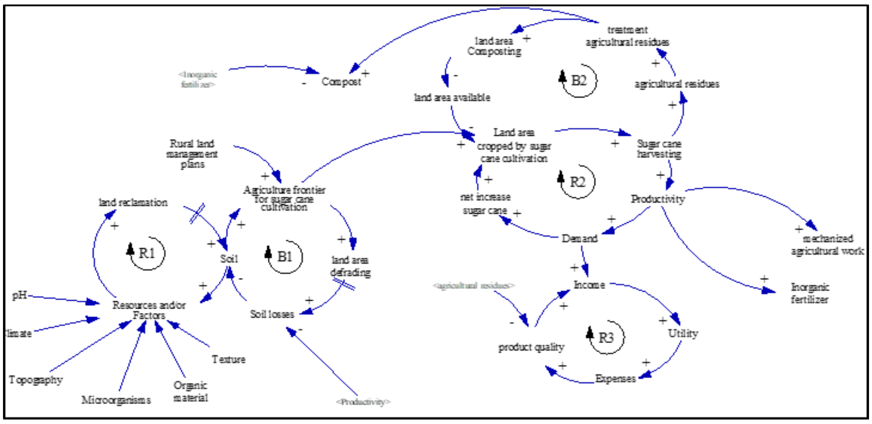


**Fig. 1.** Sugarcane cultivation influence diagram.

# 3 Results

## 3.1 Diagram of Influences

Figure 1 shows the relationship of the feedback loops, whether positive or negative, of the different variables involved in the appropriate land use for crop production (specifically for sugarcane). Each positive feedback or reinforcement loop (R1, R2 and R3) is described below and is understood as the variation of a propagating variable, reinforcing the initial variation, and tending to generate both growth behavior and negative feedback or compensation (B1 y B2).These indicate that the variation of a variable determines what counteracts the initial transition and tends to generate equilibrium behavior [25, 26].

Positive feedback or reinforcement loops are:

**R1:** represents that within greater availability of Resources (pH, climate, Topography, microorganism, organic matter, and texture), there is greater soil recovery, leading to more soil availability over time (with the conditions for use in agricultural activities) [1, 27].

**R2:** represents that the greater the sugarcane cultivation's area sown, the greater the yield will be, which leads to an increase in productivity. This will be bound to the product's increased demand, resulting in a rising effect on the cane net's increase [3,28].

**R3:** demonstrates that higher incomes with the cultivation of sugarcane, lead to the generation of greater profits, being one of the most representatives and with the greatest contribution of Gross Domestic Product in the agricultural sector. Therefore, the sugar sector has implemented improvement strategies and processes investments, which in turn have improved the crop's productivity and the product's quality [14, 19, 29].

Negative feedback loops, or compensation ones are:

**B1:** shows that the higher the land use, the more degradation problems will arise, leading to gradual losses of soil and making the resource less available, with soil's over-use or overexploitation. Land and soil degradation refer to the negative decrease or alteration of one or more ecosystem's offerings and environmental goods, services and/or functions. This is caused by natural or man-made processes which, in critical cases, may cause the loss or destruction of the environmental component [30].

**B2:** shows the relationship between the use of organic waste and the area available after the soils are recovered. The more waste is used as compost for organic waste, the more can be returned as fertilizer, conditioner, or supplement for fertilization. As a result, the physical, chemical, and biological properties improve, leading to a more environmental alternative, reducing costs at the level of fertilization, and minimizing the impact generated by soil degradation) [31].

### 3.2 Forrester's Diagram

Figure 2 shows the basic variables that give the movement to the system and are indicated as "Level", which were taken to perform the simulation associated with the production of sugarcane cultivation and its relationship to the use of land suitable for the development of such crops:

- Sugarcane planting is associated with factors such as cultivation area, preparation time of the soil and the area that is destined for the agricultural vocation. In addition, the area of soil degraded by the compaction factor was considered, which is associated with the demand of the crop and its harvest (see Fig.2A).
- For the sugarcane's production and harvesting process, the response is given to the demand's satisfaction and production's sales (see Fig.2B).
- The use of organic wastes in the sugarcane's production involves the generation of wastes from the process of composting that will be used in the soil for their improvement and up to their processing (see Fig.2C).
- Some variables associated with the income and expenses that are considered in the sugarcane's production process, were considered for the profit flow (see Fig.2D).

Now, the result of the two evaluated scenarios will be presented: where A represents the income-to-expenses ratio discharges, B shows the relationship between the costs of inorganic fertilizers and those produced by the resulting composting process, C shows the correspondence between the area to be cultivated and the sown area, and D shows the generation's residues behavior and how the compost is consumed when it is used as organic fertilization.

- **Scenario 1** - Sugarcane cultivation with compost application

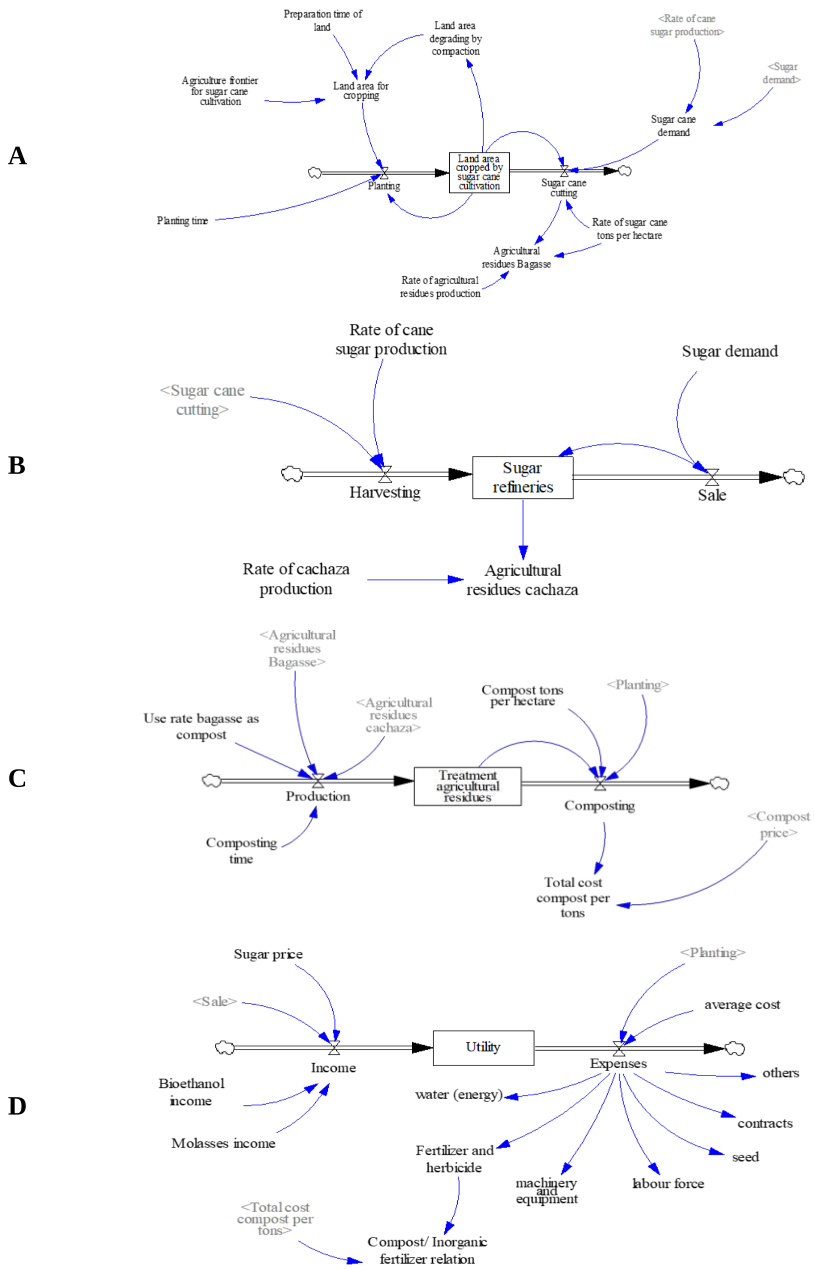


**Fig. 2**. Resulting Forrester diagram for cane cultivation.

Figure 3 shows the result stated in scenario 1 for the Forrester diagram in sugarcane cultivation.

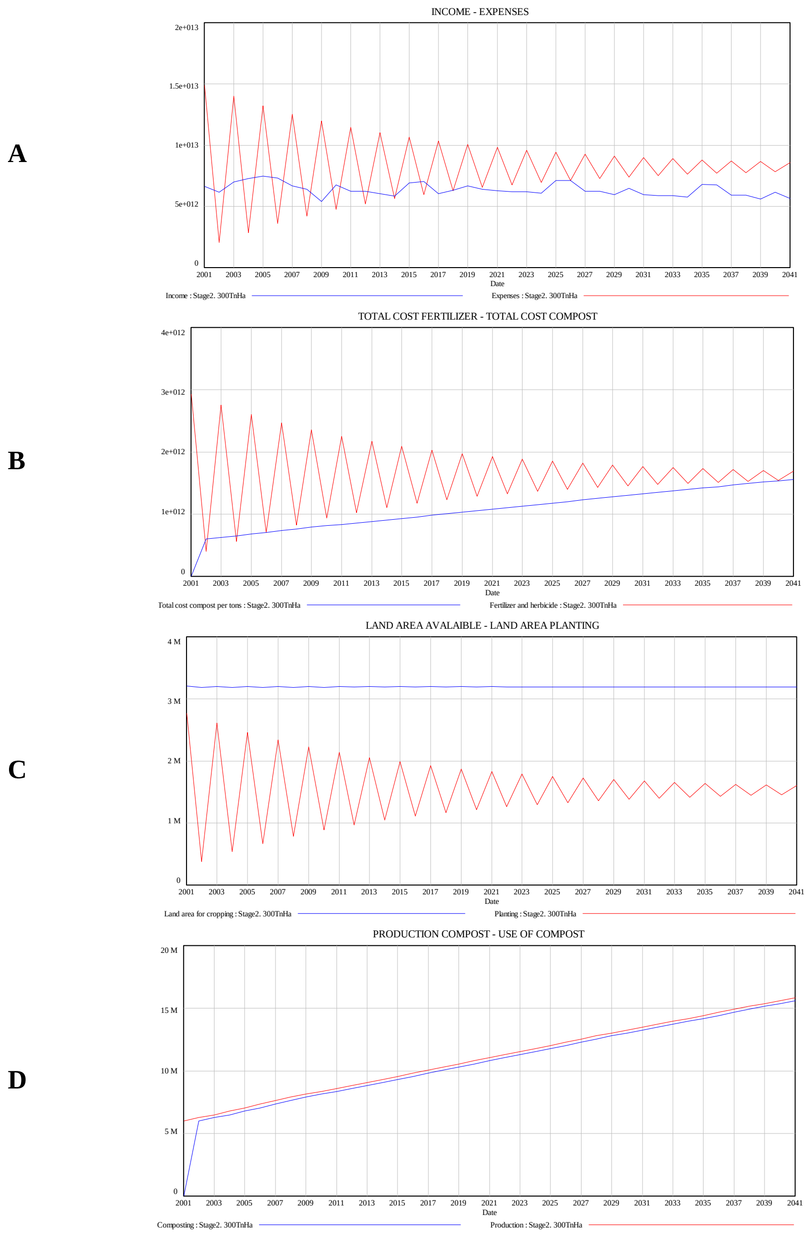


**Fig. 3.** Scenario 1 - Forrester diagram in sugarcane crop.

– **Scenario 2 -** Sugarcane cultivation without compost application

Figure 4 shows the outcome of the proposed approach for Scenario's 2 outcome.

A

B

C

D

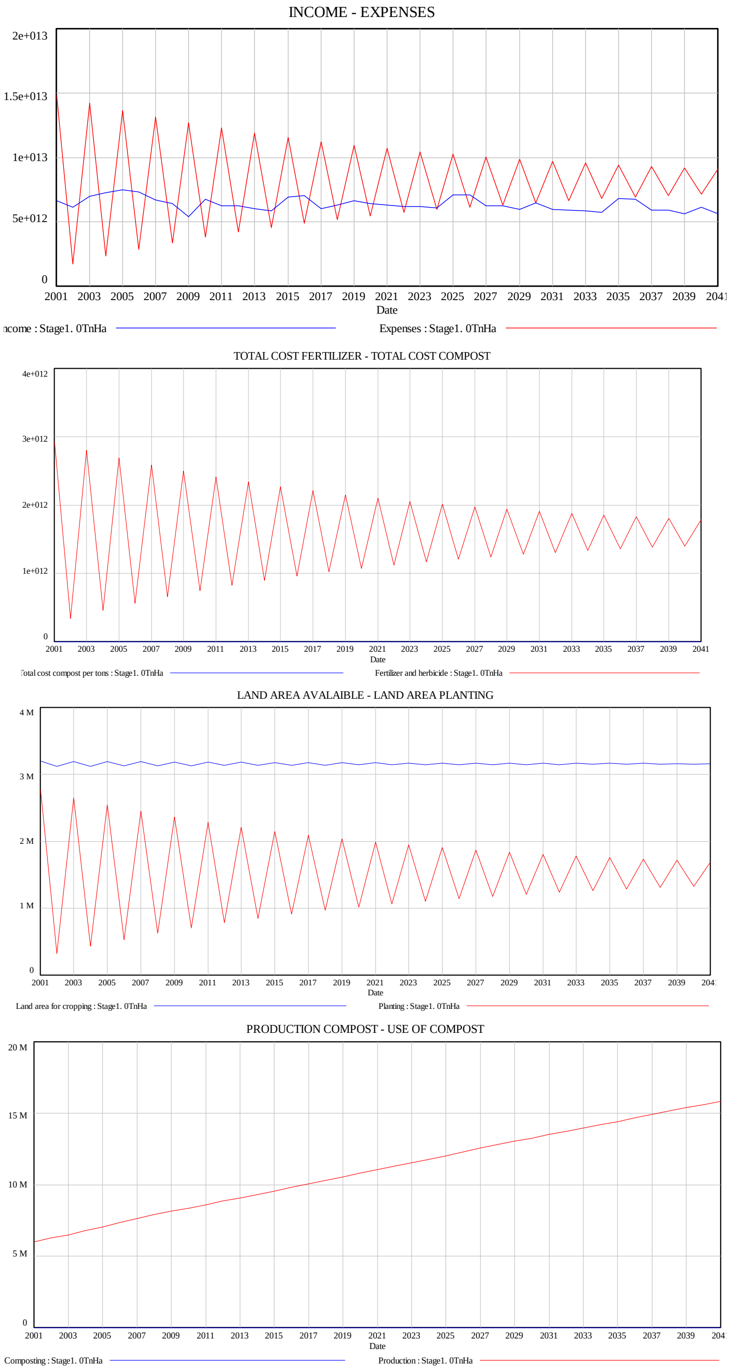


**Fig. 4.** Scenario 2 - Forrester diagram in sugarcane crop.

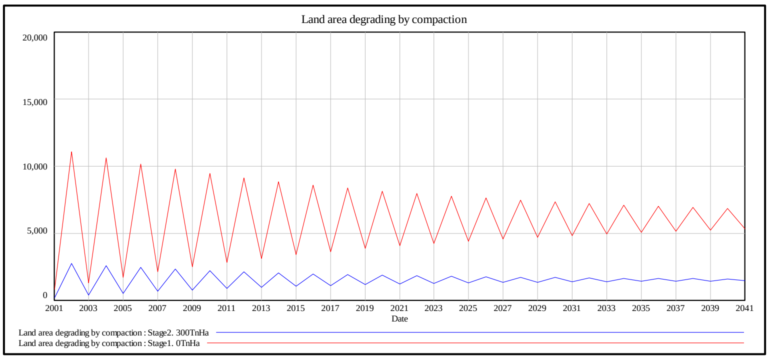


**Fig. 5.** Approach of soil's degraded area by compaction for both scenarios.

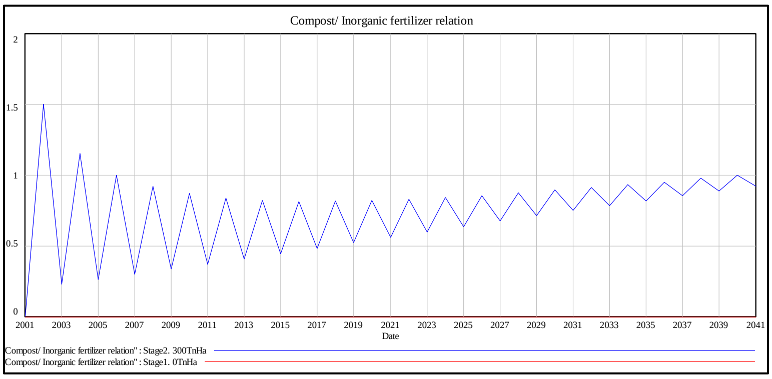


**Fig. 6.** Approach on the compost/fertilizer cost ratio over the sown area.

When comparing the two scenarios, it can be shown that a positive impact is generated by making use of the by-product resulting from the organic's composting waste generated in the sugarcane's cultivation. By compaction, there is a soil degradation reduction and, as well, it favorably affects the economic aspect since the cost associated with the use of compost is lower than the costs incurred for inorganic fertilization. We also observe the close relationship between the generation and consumption of compost within the process, which means that all the compost generated can be used in soil recovery tasks through organic fertilization.

Figure 5 shows the influence of the organic waste's usage on the soil's degradation variable by compaction. For this case, with a crop such as sugarcane it is evidenced that the use of compost from the cachaça's and bagasse's composting contributes to the mitigation of the gradual's degradation impact in the 40-year observation window over land use.

Figure 6 shows that the cost of composting ranges from 0.3 to 1.5 (percentage of the compost's cost proportion vs the fertilizers and herbicides cost), indicating that its cost is of greater benefit than inorganic fertilizers. Additionally, the area to be sown meets the demand's requirements and leads to costs reduction assumed by inorganic fertilization.

In a review of related topics, it was evident that there are no similar studies focused on the use of soil associated with the organic waste's usage versus production and improvement of costs compared to the production processes of sugarcane cultivation. Nevertheless, certain studies were found, such as the application of system dynamics in the evaluation of the Bioethanol Production Potential from Panel-Cane: dynamics between contamination, food safety and land studies [24]. In this study, the Colombian's panel-cane was characterized for producing agro-fuels in Colombia and it evaluated the influence of oil's price in sugar and panel.

Another case study found is The Systemic Approach to Sustainability in Bioethanol Production, which interconnected the production's process indicators to qualitatively highlight the main attributes of the system [25].

## 4 Conclusions

The utilization of the cachaça's and bagasse's composting by-product resulting from the sugarcane production process may contribute greatly to reducing the soil's loss and degradation (currently occurring in the world due to extensive cultivation practices such as that of sugarcane in Colombia).

The incurred costs to carry out the composting process can be recovered gradually over time, since carrying out the soil's restoration process with the same by-products leads to the fertilizer's investments cost reduction. In addition, it was evident that the generated waste was consumed entirely in the process, which means that there is no loss of the obtained composting. According to the requirements established by the crop, the compost generated would be entirely consumed and would not meet the needs of the crop, so the use of compost is more a complement than a replacement for chemical fertilization.

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